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Tennessee Valley Authority
Division of Water Control Planning
Hydraulic Data Branch

EFFECT OF ACCIDENTAL SPILLAGE OF RADIOACTIVE WASTE INTO CLINCH RIVER

Report No. 1

TIME OF TRAVEL, PROBABLE FLOWS, AND DISPERSION

Knoxville, Tennessee
November 10, 1952

Accuracies to be expected in this study: dilutions $\pm$ 10 percent, volume of flow $\pm$ 10 percent, time of travel -10 to -20 percent (that is, the value given may be 10 to 20 percent below those which will actually be observed in the field)

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In connection with studies being made by the Atomic Energy Commission of the potential hazard at downstream locations that may result from the release of radioactive contaminants into Clinch River in the vicinity of the Oak Ridge National Laboratory, certain data are needed on several factors concerned with the flow of water through TVA reservoirs. These data are directly related to the operation of the multiple-purpose system of reservoirs by TVA and can be supplied only by TVA.

This report gives the results of the initial portion of investigations being made to supply these data and relates to the first three items of information requested by Dr. Karl Z. Morgan, Director of the Health Physics Division, ~~A.E.C.~~ O.R.N.L., in his letter of January 29, 1952, to Dr. O. M. Derryberry, Director of Health, TVA. These three items are:

1. Time of water travel under normal (or average) conditions from Clinch River mile 20.8 to downstream points, including Clinch River miles 13.2 and 4.4, Emory River mile 12.8, Tennessee River miles 567.7 and 465.3 during (a) non-stratified and (b) stratified flow conditions. Plate 1 shows the relative geographical location of these points.

2. Probable discharge at each of these points and consequent dilution, assuming mixing at the source (Clinch River mile 20.8) and considering stratification if it exists.

3. Reduction in peak concentration (due to dilution and dispersion alone) and duration of concentration exceeding 1 percent of the initial concentration (after mixing at Clinch River mile 20.8) for each of the points in (1) assuming uniform rate of discharge of wastes at Clinch River mile 20.8 over a period of (a) six hours, (b) one day, (c) one week, (d) twenty days.

Over a long period and covering a wide range of reservoir operations, Hydraulic Data Branch engineers have accumulated much data concerning temperature and flow conditions in many TVA reservoirs. These data provide excellent basic information for solving the problems posed by Dr. Morgan. In particular, surveys of water temperatures and alkalinities for studies of the Harriman, Tennessee, water pollution situation which were made every month over a period of several years, time of water travel investigations in Fort Loudoun Reservoir, and observations of water temperatures and velocities in Clinch River recently made in studies for the Kingston Steam Plant provide valuable basic data useful in this study.

Characteristics of Flow Through Reservoirs

Two basic conditions exist in most TVA reservoirs which affect the general flow pattern. These conditions occur at different seasons of the year and are dependent upon whether or not the water in the reservoir becomes thermally stratified. In a series of reservoirs, temperature of water released from upstream reservoirs has an important part in the thermal stratification and flow through the downstream reservoirs. In general, stratified flow occurs during the late spring and summer months. During the remainder of the year, non-stratified flow occurs, as stratification does not exist during that time.

During the non-stratified flow period, water flows through a reservoir occupying an effective area of flow which is almost the entire cross section of the reservoir. Water in the reaches of embayments beyond the effective area of flow is subject to gradual replacement by diffusion which has no appreciable effect on the longitudinal movement of the principal flow.

When this normal flow condition exists, the average velocity of the water flowing past a given point is equal to the total discharge divided by the effective area normal to the flow at that point. The time of water travel between points in a reservoir is then equal to the distance between those points divided by the average velocity.

But during the period of thermal stratification, flow through a reservoir follows a very different pattern which has an important influence on time of water travel through a reservoir.

Phenomena of Flow During Thermal Stratification

In general, thermal stratification occurs during the period May through September. This period may vary at each end of the change-over by about a month. In Watts Bar Reservoir this phenomenon is due to a combination of the heating of the water surface by solar radiation, the lower temperatures of the discharges from the upstream tributary reservoirs, Norris and Calderwood, and the cool water from Douglas and Cherokee Reservoirs which flows through Fort Loudoun Reservoir into Watts Bar Reservoir. During the stratification period a large portion of the inflow into Watts Bar Reservoir is from the upstream tributary reservoirs which are discharging cold waters. At this time of year, the heat gain due mainly to solar radiation exceeds the heat losses due to evaporation, back radiation, convection, and conduction. As a result, the upper strata of water become warmer than the lower strata. All of the water is above the temperature of maximum density (39.2°F) so that the warmer the water the lighter is its density. It follows then that stratification will occur with the coldest water on the bottom and the warmest on top provided no other forces exist to break up this occurrence. Such forces will result when flows are great enough to cause appreciable turbulence. This turbulence will break up the stratification in Watts Bar Reservoir, because the reservoir is relatively shallow, and stratification in this reservoir is an induced rather than a natural phenomenon.

When the flow into Watts Bar Reservoir is less than that which produces appreciable turbulence, waters flowing into the reservoir seek levels consistent with their temperatures. If these inflowing waters are as cold as any water in the reservoir, their level will be on the bottom. If they are intermediate in temperature between the extremes of temperatures existing in the reservoir, an interflow will occur. If the inflow is as warm as surface water temperatures, flow will be through the surface layer.

In this study, specific interest during stratified conditions is in the flow phenomena in the Clinch River embayment below Clinch River mile 20.8, in the Emory River embayment below Emory River mile 12.8, and in the main Watts Bar Reservoir below the mouth of the Clinch River.

Thermal stratification will exist in the Clinch River embayment above the mouth of the Emory River whenever Clinch River flows do not exceed about 7000 cubic feet per second. For discharges greater than this sufficient turbulent mixing occurs to break up or prevent stratification. This limit has been determined by field measurements to correspond to a velocity of about 0.5 foot per second.

A Clinch River flow of about 1000 cubic feet per second or less will gain sufficient heat in traversing the river channel between Norris Dam and the backwaters of Watts Bar during the stratified flow period to make it warmer than the bottom layers in the Clinch River embayment yet colder than the surface layers. As a result, these lower flows move as interflows. By the time the main Watts Bar Reservoir is reached the Clinch River water is unidentifiable as a separate stratum. This circumstance is due to its mixing with the water in the lower end of the Clinch River embayment and with the inflowing waters of Fort Loudoun and Calderwood Reservoirs.

Clinch River water will move up the Emory River embayment during the stratification period when the flow from the Emory River is less than about 500 cubic feet per second. The forces causing this flow are derived from the difference in densities due to temperature and from the viscous shear between the fairly well defined strata. The distance Clinch River water moves up the Emory River depends upon the magnitude and duration of the Clinch River discharge. The data indicate that a Clinch River discharge of at least 3000 cubic feet per second maintained for about a week is required to give the necessary strata depth to cause these waters to move up the Emory River embayment as far as the Harriman water plant intake at Emory River mile 12.8. Movement up the Emory River on the bottom or on the top depends upon whether the Clinch River water is colder or warmer than the water flowing out of the Emory River. This movement is very slow, varying between 0.6 mile per day at the lower flows to 1.0 mile per day at higher flows. However, a flow out of the Emory River of more than 500 cubic feet per second is sufficient to push the Clinch River water downstream away from the Harriman water intake.

Occasions will arise near the end of the stratified flow period in the fall when the Clinch River water is warmer than the Emory River water. As the Emory River water flows downstream along the bottom, the warmer Clinch River water will move upstream along the top due to longitudinal circulation. Since the Emory River flow is usually low at this time, the Clinch River water will move upstream beyond the intake and at an elevation higher than that of the intake, gradually cooling to the Emory River temperature. The cooled Clinch River water will then mix with the downstream Emory River flow on the bottom and will be drawn, though dilute, into the water plant.

Observed data between 1944 and 1948 during the stratified flow period show that a steady Clinch River discharge of about 6000 cubic feet per second maintained its identity as a separate stratum flowing at the bottom of Watts Bar Reservoir all the way to the dam. The mass of water contained in this flow is so large that it does not readily mix with overlying strata. Furthermore, Norris releases over 6000 cubic feet per second are usually more steady flows than lesser rates. The lesser rates of flow are usually unsteady and mix with other inflowing waters in Watts Bar Reservoir. This mixing prevents these flows from remaining separate strata in that portion of the reservoir.

No data are available for temperatures in Watts Bar Reservoir when Clinch River flows exceed Norris turbine capacity (about 8500 cubic feet per second). Such flows in the stratified flow period are unusual. However, should they occur, the entire cross-section of the Clinch embayment would be filled with cold Norris water. With relatively low flow in the main river below the mouth of the Clinch River, this cold water would flow as a separate stratum at the bottom of Watts Bar Reservoir. If the total flow into Watts Bar Reservoir is large enough to require the entire cross-section, the inflowing Clinch water would become indistinguishable as a separate stratum. The rate of travel would then be a function of this total flow through Watts Bar Reservoir rather than of the Clinch River flow alone. When this total flow exceeds about 50,000 cubic feet per second, stratification in Watts Bar is broken up and becomes non-existent. The rate of water travel is then that of non-stratified flow.

Observed data from temperature surveys in Chickamauga Reservoir show that stratification in that reservoir occurs only at the extreme lower portion near the dam so that flow through Chickamauga Reservoir is treated as non-stratified.

Time of Water Travel

Non-Stratified Flow Conditions

Non-stratified flow conditions due to temperature exist from about October through April in the Clinch River embayment of Watts Bar Reservoir and in the main reservoir. Plate 2 shows the variation of time of water travel with steady discharge and pool elevation during non-stratification in the Clinch River from mile 20.8 to downstream points on the Clinch River. Plate 3 shows the time of water travel during non-stratification in Watts Bar Reservoir from the junction of the Clinch and Tennessee Rivers at Tennessee River mile 567.7 to Watts Bar Dam at Tennessee River mile 529.9. Plate 4 shows the time required for various steady discharges to pass from Tennessee River mile 529.9 to the Chattanooga water plant intake at Tennessee River mile 465.3. Since Chickamauga Reservoir has practically no stratification through the year, Plate 4 is applicable to year-round flow conditions. In general, the time of water travel between two points for a given pool elevation varies inversely with the discharge.

Normally, during this period, there will be no movement of Clinch River water up the Emory River embayment to mile 12.8, the location of the Harriman water plant intake. However, if the level of Watts Bar Reservoir is raised at such a rate that the inflow from the Emory River is less than the storage rate in the Emory River arm some Clinch River water will flow into this embayment. In a flood regulation the usual rate of storage in the Emory River arm of Watts Bar Reservoir is less than the rate of inflow from Emory River during the non-stratification period.

Stratified Flow Conditions

Clinch River--Plate 5 shows the time of water travel from Clinch River mile 20.8 to downstream points on the Clinch River with Watts Bar Reservoir at elevation 740 which is about the mean level during the period when stratified conditions prevail. For discharges less than 7000 cubic feet per second there is an appreciable shortening in time of travel to downstream points compared to non-stratified conditions as may be seen from a comparison of Plates 2 and 5. When Clinch River flows exceed about 7000 cubic feet per second, stratification does not occur in this embayment above the mouth of the Emory River and does not occur in the entire embayment when flows exceed 10,000 cubic feet per second.

Emory River--During the period of stratified flow some Clinch River water will flow up the Emory River on the bottom as far as the Harriman water plant intake at mile 12.8 under certain conditions. These conditions are:

1. A Norris Dam release of at least 3000 cubic feet per second is required to provide sufficient cold water depth to reach the intake.

2. Daily average discharges from Norris Reservoir of 3000 cubic feet per second or more must be continued for about a week in order for the cold water to reach this intake.

3. A flow from the Emory River of less than 500 cubic feet per second is required to permit the Clinch River water to reach the intake. (A flow of more than 500 cubic feet per second occurs slightly under 50 percent of the time during the stratified flow period and seldom for long durations.)

The movement of the Clinch River water up the Emory River embayment to the Harriman water plant intake is very slow, requiring about 21 days when the Norris release is about 3000 cubic feet per second and about 12 days when it is about 5000 cubic feet per second.

Watts Bar Reservoir--From the occasions that it has been possible to identify Clinch River water from the isothermal patterns between Tennessee River miles 567.7 and 529.9, it has been found that:

1. A Clinch River discharge over about 6000 cubic feet per second will travel as a distinguishable water mass between Tennessee River miles 567.7 and 529.9 in about six and one-half days when the total flow through Watts Bar Reservoir is less than about 50,000 cubic feet per second.

2. A Clinch River discharge less than 6000 cubic feet per second does not travel as a distinguishable water mass but mixes with other releases flowing into Watts Bar Reservoir. Under this condition the mixture moves through the reservoir as a deeper stratum than would Clinch water alone. The time of travel is dependent on the total flow through the reservoir. Between miles 567.7 and 529.9 it varies uniformly from seven and one-half days for a total flow of about 20,000 cubic feet per second to four and one-half days for about 50,000 cubic feet per second.

3. When Watts Bar inflows exceed about 50,000 cubic feet per second, stratification no longer exists. The time of travel is then determined from Plate 3 for non-stratified flow conditions.

Chickamauga Reservoir--As no appreciable stratification occurs in Chickamauga Reservoir, the curves for time of water travel shown on Plate 4 cover year-round conditions.

Accuracy

The average times of water travel obtained from Plates 2, 3, 4, and 5 may be 10 to 20 percent lower than values actually observed in the field.

Observed Time of Water Travel during Accidental Spillage of Radioactive Waste in May 1952

In May 1952 a minor accidental spillage of radioactive waste into White Oak Creek occurred. This spillage provides data sufficiently pertinent to warrant recording in some detail. Samples were taken by the Oak Ridge National Laboratory below the dike forming White Oak Lake less than a mile above the junction of the creek with the Clinch River at mile 20.8. Samples were also taken by the K-25 Health Physics Section at the K-25 steam plant intake at Clinch River mile 13.2. One daily grab sample was taken about 11:00 a.m. each day from May 22 to June 25 below the dike. A 48-hour composite sample was taken at the lower point during the same period. A portion of the results are shown on Plate 6. An attempt was made to draw a smooth distribution graph for each station. Due to the method of measuring radioactivity at the lower station the probable errors are large. However, the trends are apparent. The hydrograph of the Clinch River near Scarboro located at mile 38.9 is reproduced in the upper portion of the plate. This hydrograph shows flow conditions during the sampling period. The time of beginning of increase in radioactivity as measured at the two points, Clinch River miles 20.8 and 13.2, shows that the time of water travel between these points is about two days. During the passage of the peak concentration the time of water travel shown by the estimated peaks is slightly over four days.

This accident occurred during the stratified flow period for which the curves of Plate 5 are applicable. To obtain the flows occurring between Clinch River mile 20.8 and 13.2, which are needed to use Plate 5, the Scarboro hydrograph must be lagged by the time of wave travel from the gage at Clinch River mile 38.9 to mile 17.0, the mid-point between the points of interest. Studies of wave travel by the Hydraulic Data Branch show that this time would be about four hours. Since the flows were unsteady the times of water travel are computed using average flows for 12-hour periods determined from the Scarboro hydrograph lagged four hours. The times of water travel corresponding to these flows can be obtained from Plate 5. These times are then arithmetically averaged to obtain the time between points of beginning of increase in radioactivity or between peaks. When flows are unsteady, a trial and error method is necessary to obtain an average over a period approximately equal to the time of water travel. The first trial may result in taking average flows over a total period not equal in duration to the time of travel. This error can be readily adjusted by lengthening or shortening the total period originally chosen until close agreement is reached between the two times.

The following tabulation will show the method used:

Between Beginnings of Increase

Date	Hour	Average Scarboro Flow-cfs	Time of Water Travel Days
May 27	8P		
		2700	1.3
28	8A		
		2500	1.4
28	8P		
		2300	1.5
29	8A		
Period:	$1\frac{1}{2}$ days	Average:	1.5 days

Between Peak Concentrations

Date	Hour	Average Scarboro Flow-cfs	Time of Water Travel-Days
May 30	8P		
		900	3.5
31	8A		
		450	6.8
31	8P		
		350	8.8
June 1	8A		
		300	10.4
1	8P		
		1100	3.0
2	8A		
		800	4.0
2	8P		
		3600	0.9
3	8A		
		2200	1.6
3	8P		
		3000	1.2
4	8A		
Period:	$4\frac{1}{2}$ days	Average:	4.5 days

No attempt was made to draw the approximated distribution graphs on Plate 6 according to the curves of Plate 5.

Probable Flows at Pertinent Points

Table 1 on page 14 gives the maximum, mean, and minimum daily flows by months at each point on the Clinch, Emory, and Tennessee Rivers requested. A mean flow for the non-stratified and stratified flow period is also given. These flows are based upon observed data between 1945 and 1951 when the reservoir system above the points was practically complete and can be considered typical with regard to operating conditions. The mean daily flow for each month shows the variation which may be expected throughout the year at each point and represents the probable flow available. The maximum and minimum daily flows for each month show the extremes which were experienced during the period 1945-1951. These values may be exceeded in the future as they are dependent upon runoff conditions and, except for the Emory River mile 12.8 data, upon power loadings at upstream hydroelectric plants.

Plates 7 to 11 show the chronological sequence of maximum, mean, and minimum flows at each requested river mile for the period 1945-1951.

Reduction in Peak Concentration

Reduction in peak concentration takes place in the reservoirs and can be attributed to two principal causes. One is the dilution of the original contaminated mass by being mixed with additional inflowing waters. The ratio of the new concentration to the original concentration will then be inversely proportional to the total flows available for dilution at each point. The other cause is the dispersion of the original mass into portions of the reservoir through which it passes with gradual diffusion into embayments. The magnitude of the reduction is dependent upon the existence of non-stratified or stratified flow conditions, the reservoir pool level, and the duration of the discharge of wastes.

Non-Stratified Flow Conditions

An estimate has been made of the reductions in peak concentration which would occur due to dispersion in passage through the reservoirs. Plates 12 to 16 show the estimated reduction in percent of initial concentration (assuming mixing at Clinch River mile 20.8) under non-stratified flow conditions at each selected downstream point. The effect of various Clinch River flows, Watts Bar Pool elevation, and the specified durations of discharge of waste at Clinch River mile 20.8 is incorporated in the plates.

There would be additional reduction in peak concentration beyond these amounts due to dilution by any increase in flow. It may be assumed that there will be no reduction in concentration due to dilution between Clinch River miles 20.8 and 13.2 as the local drainage area is very small.

Stratified Flow Conditions

The characteristics of this flow condition are such as to yield much less reduction in peak concentration due to dispersion than during non-stratified flow conditions. The volume of water in which dispersion occurs at this time varies with the magnitude of the discharge and its stratum location. This reduction is estimated for two assumed simple cases of stratified flow with the total flow through Watts Bar Reservoir less than 50,000 cubic feet per second. One case is for a Clinch River flow of 3000 cubic feet per second which mixes with other releases flowing into Watts Bar Reservoir and moves as a deeper stratum than would the Clinch water alone. The other case is for a Clinch River flow of 6000 cubic feet per second which does not mix but flows as a distinguishable stratum at the bottom of Watts Bar Reservoir. Table 2 on page 15 shows the estimated reduction in peak concentration due to dispersion for these two assumed flow conditions for each point requested. These tabulated values are for peak concentration in the bottom stratum and represent the highest concentration at any point in the cross-section, not averages in the entire section. The results shown in Table 2 for Emory River mile 12.8 should be regarded as probably the least reduction which will occur under any stratified flow condition. Changing flow patterns in the Clinch River and in the Emory River would result in greater reductions due to the creation of additional turbulence and consequent mixing with more of the water in the Emory embayment.

There will be reduction in peak concentration by dilution in addition to that due to dispersion shown in Table 2, which will depend upon the magnitude of the Norris release. The magnitude determines whether the stratum remains separate or mixes. The quantity of water available for dilution is dependent upon existing flows. In addition to reduction in peak concentration by dispersion, it is expected that:

1. If the Norris release is less than 1000 cubic feet per second, reduction in peak concentration by dilution will occur in the Clinch River embayment to its mouth.

2. If the Norris release is more than 7000 cubic feet per second, reduction in peak concentration by dilution will occur in the Clinch River embayment to the mouth of the Emory River (Clinch River mile 4.4) and in the Clinch River embayment to its mouth (Tennessee River mile 567.7) when the Norris release is more than 10,000 cubic feet per second.

3. If Clinch River water is at the Harriman water plant intake during the stratified flow period, reduction in peak concentration will occur whenever the Emory River flows exceed 500 cubic feet per

second. Near the end of the stratified flow period when Emory River discharge is low and colder than Clinch River water, there will be additional reduction in peak concentration by dilution at the Harriman water plant intake from the Emory River flows.

4. If the Norris release is less than 6000 cubic feet per second, there will be reduction in peak concentration by dilution at the Watts Bar Dam water plant, Tennessee River mile 529.9.

5. There will be reduction in peak concentration by dilution at the Chattanooga water plant intake at all times as no significant stratification occurs in Chickamauga Reservoir.

Accuracy

The reductions in peak concentrations obtained from Plates 12, 13, 14, 15, and 16 and shown in Table 2 may deviate ±5 percent from values actually observed.

Duration of Concentration

Studies are in progress with respect to duration of concentration and will be reported upon at a subsequent time.

ACKNOWLEDGMENTS

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Tennessee Valley Authority
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TABLE 1

Maximum, Mean, and Minimum Daily Flows in Cubic Feet Per Second

Clinch, Emory, and Tennessee Rivers
1945-1951

	CLINCH RIVER						EMORY RIVER		
	Miles 20.8 and 13.2			Mile 4.4[b]			Mile 12.8		
Month	Maximum	Mean	Min.	Maximum	Mean	Min.	Maximum	Mean	Min.
Jan.	22,900	8,960	1,620	70,700	14,400	2,120	50,000	4,450	178
Feb.	27,700	10,100	1,230	89,800	15,800	2,250	69,000	4,550	468
Mar.	12,700	5,850	690	26,700	9,450	1,830	15,400	2,910	507
Apr.	8,540	3,400	306	13,300	5,620	752	6,660	1,800	249
May	8,080	2,750	298	19,700	4,700	520	13,100	1,610	58
June	7,420	2,820	224	9,280	3,320	262	5,300	396	14
July	7,630	2,930	259	12,800	3,400	281	9,230	360	21
Aug.	8,390	4,520	374	9,760	4,800	378	3,060	177	4
Sept.	8,450	4,620	341	13,000	4,940	462	5,500	224	2
Oct.	9,200	5,130	150[a]	14,200	5,300	150[a]	5,040	93	1
Nov.	12,700	4,430	453	40,500	5,830	556	27,800	1,100	2
Dec.	27,000	8,360	569	60,300	11,700	593	33,300	2,720	24
Oct.-Apr.[1]		6,600			9,730			2,520	
May-Sept.[2]		3,530			4,230			553	

	TENNESSEE RIVER					
	Mile 529.9			Mile 465.3		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
Jan.	181,000	47,700	15,800	218,000	63,900	23,200
Feb.	204,000	50,800	17,900	195,000	67,900	19,700
Mar.	100,000	32,400	13,300	148,000	44,200	19,500
Apr.	43,700	23,800	5,200	82,000	27,700	13,200
May	38,300	20,000	3,000	95,900	28,800	17,900
June	32,100	18,900	8,200	32,800	25,500	18,900
July	87,500	19,600	6,500	106,000	26,400	15,400
Aug.	37,600	21,400	9,900	43,300	28,100	17,800
Sept.	39,900	22,200	6,900	54,400	30,100	17,100
Oct.	67,100	23,500	9,800	72,800	29,700	16,300
Nov.	128,000	25,400	10,300	167,000	34,000	13,600
Dec.	112,000	41,000	11,800	139,000	53,600	21,100
Oct.-Apr.[1]		34,900			45,900	
May-Sept.[2]		20,400			27,800	

1. Non-stratified flow period.
2. Stratified flow period.

a. On August 28, 1943, TVA agreed to maintain a flow of at least 150 cubic feet per second in the Clinch River for the benefit of Oak Ridge.
b. Flows shown for Clinch River mile 4.4 include the Emory River flows.

October 6, 1952

Tennessee Valley Authority
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TABLE 2

Reduction in Peak Concentration

Due To Dispersion

Stratified Flow Conditions

Clinch River Flow 1000 cfs	Duration* Days	Percent Reduction of Initial Concentration at Cl. 20.8 Clinch River M 13.2	Clinch River M 4.4	Clinch River M 0	Emory River M 12.8	Tennessee River M 529.9	Tennessee River M 465.3
3.0	1/4	38	66	76	72	97	99
6.0	1/4	21	51	69	64	82	96
3.0	1	4	26	40	34	90	95
6.0	1	0	12	30	25	51	85
3.0	7	0	0	0	0	52	72
6.0	7	0	0	0	0	2	42
3.0	20	0	0	0	0	22	44
6.0	20	0	0	0	0	0	14

* Duration of uniform discharge of wastes at Clinch River M 20.8 where mixing is assumed.

October 6, 1952

APPENDICES

Accompanying are two appendices. Appendix A gives the drainage areas in square miles above pertinent points. Appendix B is a sample computation illustrating the use of the basic curves accompanying this report.

APPENDIX A

DRAINAGE AREAS ABOVE PERTINENT POINTS

Clinch River

	Square Miles
Mile 79.8 (Norris Dam)	2912
Mile 38.9 (Scarboro gage)	3300
Mile 20.8 (above White Oak Creek)	3347
Mile 13.2 (K-25 Steam Plant Intake)	3387
Mile 4.4 (excluding Emory River)	3541
Mile 4.4 (including Emory River)	4406
Mouth	4413

Emory River

	Square Miles
Mile 18.3 (Oakdale)	764
Mile 12.8 (Harriman Water Plant)	798
Mouth	865

Tennessee River

	Square Miles
Mile 567.7 (excluding Clinch River)	12,470
Mile 567.7 (including Clinch River)	16,883
Mile 529.9 (Watts Bar Dam)	17,310
Mile 465.3 (Chattanooga Water Plant)	21,390

APPENDIX B

ILLUSTRATIVE EXAMPLE OF USE OF BASIC CURVES

Given: March mean discharge data (taken from Table 1).

Discharges at:	Clinch River miles 20.8 and 13.2	5,850 cfs
	Emory River mile 12.8	2,910 cfs
	Clinch River mile 4.4 (below Emory)	9,450 cfs
	Tennessee River mile 529.9 (Watts Bar Inflow)	32,400 cfs
	Tennessee River mile 465.3 (Chattanooga discharge)	44,200 cfs

Watts Bar Headwater	El. 736
Chickamauga Headwater	El. 676
Duration of waste spillage	1 day

Desired: Average time of water travel from Clinch River mile 20.8 to Clinch River miles 13.2 and 4.4, and to Tennessee River miles 567.7, 529.9, and 465.3. Also, the reduction in peak concentration at each of these points due to dispersion and dilution only.

Since the data given are for March, non-stratified flow conditions exist, and plates for this period are applicable.

A. Time of Water Travel

From Clinch River mile 20.8 to 13.2

The discharge of 5,850 cubic feet per second at Clinch River mile 20.8 is taken as the average discharge between Clinch River miles 20.8 and 13.2 since the intervening drainage area is small (see Appendix A), and local inflow can be neglected.

Enter Plate 2 with an abscissa of 5,850 cubic feet per second for the Clinch River Discharge and at the intersection with the line marked Watts Bar Headwater Elevation 736, on the lowest set of curves, which apply for this reach, read on the ordinate scale the Time in Days from Clinch River mile 20.8. The closest one-quarter day will be read in this example.

Average time of water travel from Clinch River mile 20.8 to 13.2 = 1/2 day.

From Clinch River mile 20.8 to 4.4

The average discharge between Clinch River miles 20.8 to 4.4 is taken as the average of the discharge at Clinch River mile 20.8 of 5,850 cubic feet per second and the discharge at mile 4.4 of 9,450 cubic feet per second reduced by the discharge of the Emory River at its mouth. The discharge of the Emory River at its mouth is the discharge at Emory River mile 12.8 of 2,910 cubic feet per second multiplied by the ratio of the drainage area (865 sq. miles) at the mouth to the drainage area at mile 12.8 (798 sq. miles), which is 865/798.

Then Emory River discharge at mouth = $2{,}910 \times \frac{865}{798} = 3{,}150$ cfs

Clinch River discharge at mile 4.4 less Emory River discharge at mouth = 9,450 - 3,150 = 6,300 cfs

Average discharge between Clinch River miles 20.8 and 4.4 = 1/2 (5,850 + 6,300) = 6,080 cfs

Enter Plate 2 with an abscissa of 6,080 cubic feet per second for the Clinch River Discharge and at the intersection with the line marked Watts Bar Headwater Elevation 736, on the middle set of curves, which apply for this reach, read on the ordinate scale the Time in Days from Clinch River mile 20.8.

Average time of water travel from Clinch River miles 20.8 to 4.4 = 1-1/2 days.

From Clinch River mile 20.8 to Mouth of Clinch River

The average discharge between Clinch River mile 4.4 and the mouth of the Clinch River is taken as the discharge of 9,450 cubic feet per second at Clinch River mile 4.4 (below Emory) since the intervening drainage area is negligible (see Appendix A). The average time of water travel between mile 4.4 and the mouth corresponding to the average discharge in this reach is added to the average time of water travel determined above for the reach between mile 20.8 and 4.4 to obtain the total time from mile 20.8 to the mouth.

Enter Plate 2 with an abscissa of 9,450 cubic feet per second for the Clinch River Discharge and at the intersections with the lines marked Watts Bar Headwater Elevation 736 on the middle and upper sets of curves read on the ordinate scales the Time in Days from Clinch River mile 20.8, 1 and 1-3/4 days, respectively. The difference between these times, 3/4 of a day, is the time of travel between mile 4.4 and the mouth of the Clinch River. Then:

Mile 20.8 to mouth (9,450 cfs)	1-3/4 days
Mile 20.8 to mile 4.4 (9,450 cfs)	1 day
Mile 4.4 to mouth	3/4 day
Mile 20.8 to 4.4 (6,080 cfs)	1-1/2 days
Mile 20.8 to mouth	2-1/4 days

From Clinch River mile 20.8 to Tennessee River mile 529.9

The average discharge between the mouth of the Clinch River at Tennessee River mile 567.7 and Watts Bar Dam at mile 529.9 is taken as the Watts Bar inflow of 32,400 cubic feet per second. The average time of water travel between these points corresponding to this discharge is added to the time determined above for the reach between Clinch River mile 20.8 and the mouth to obtain the total time from Clinch River mile 20.8 to Tennessee River mile 529.9.

Enter Plate 3 with an abscissa of 32,400 cubic feet per second for the Watts Bar Inflow and at the intersection with the line marked Watts Bar

Headwater Elevation 736 read on the ordinate scale the Time in Days from Tennessee River mile 567.7 to mile 529.9, 7-1/4 days. Then:

Tennessee River mile 567.7 to 529.9	7-1/4 days
Clinch River mile 20.8 to mouth	2-1/4 days
Clinch River mile 20.8 to Tennessee River mile 529.9	9-1/2 days

From Clinch River mile 20.8 to Tennessee River mile 465.3

The average time of travel between Tennessee River miles 529.9 and 465.3 is based on the discharge at Chattanooga of 44,200 cubic feet per second. Then this time is added to the time determined above for the reach between Clinch River mile 20.8 and Tennessee River mile 529.9 to obtain the total time from Clinch River mile 20.8 to Tennessee River mile 465.3.

Enter Plate 4 with an abscissa of 44,200 cubic feet per second for the Chattanooga Discharge and at the intersection with the line marked Chickamauga Headwater Elevation 676 read on the ordinate scale the Time in Days from Tennessee River mile 529.9 to mile 465.3, 3-3/4 days. Then:

Tennessee River mile 529.9 to 465.3	3-3/4 days
Clinch River mile 20.8 to Tennessee River mile 529.9	9-1/2 days
Clinch River mile 20.8 to Tennessee River mile 465.3	13-1/4 days

B. Reduction in Peak Concentration Due to Dispersion and Dilution

The Clinch River Discharge at mile 20.8 of 5850 cubic feet per second is used in Plates 12, 13, 14, 15, and 16 as the ordinate to determine the reduction due to dispersion. The Duration 1 Day of waste spillage and the Watts Bar Headwater Elevation 736 given in this example are the parameters used in the Plates 12, 13, 14, and 15. Plate 16 requires, in addition, the Chickamauga Headwater Elevation 676.

The reduction in peak concentration due to dilution is determined from the flows available at each point. The total reduction is equal to the products of the concentration remaining at the point (after dispersion and dilution) subtracted from unity.

At Clinch River mile 13.2

By dispersion for 1 day duration from Plate 12	0 percent
By dilution (since flow at mile 13.2 was assumed same as at mile 20.8	0 percent
Total reduction	0 percent

At Clinch River mile 4.4

By dispersion from Plate 13	5 percent
By dilution = $100\ (1 - \frac{5,850}{9,450})$	38 percent
Total reduction = $100\ [1 - (1 - 0.05)\ (1 - 0.38)]$	41 percent

At mouth of Clinch River

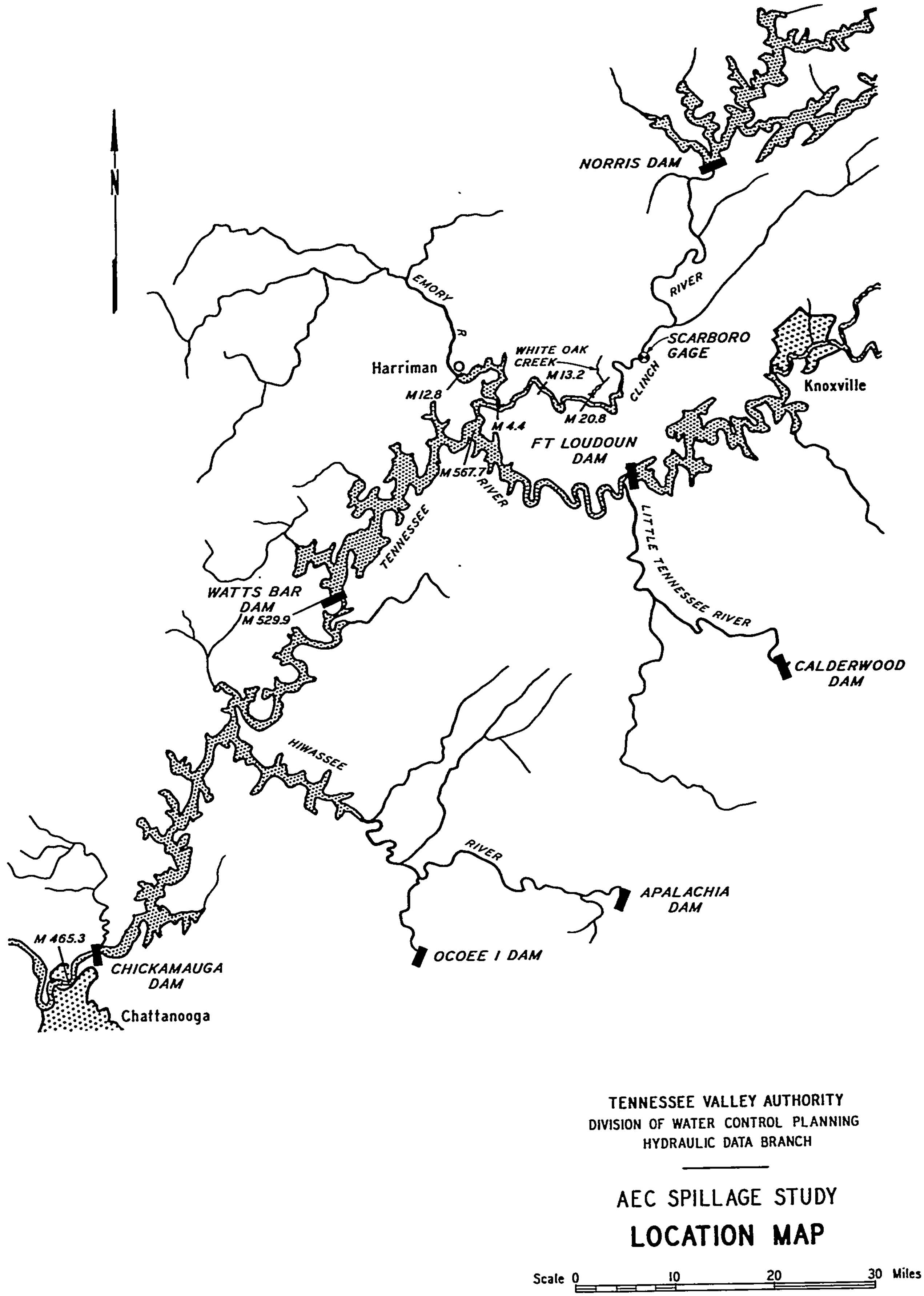
By dispersion from Plate 14	19 percent
By dilution (assuming no local inflow between mile 4.4 and the mouth)	38 percent
Total reduction = $100\ [1 - (1 - 0.19)\ (1 - 0.38)]$	50 percent

At Tennessee River mile 529.9

By dispersion from Plate 15	85 percent
By dilution = $100\ (1 - \frac{5,850}{32,400})$	82 percent
Total reduction = $100\ [1 - (1 - 0.85)\ (1 - 0.82)]$	97 percent

At Tennessee River mile 465.3

By dispersion from Plate 16	91 percent
By dilution = $100\ (1 - \frac{5,850}{44,200})$	87 percent
Total reduction = $100\ [1 - (1 - 0.91)\ (1 - 0.87)$	99 percent



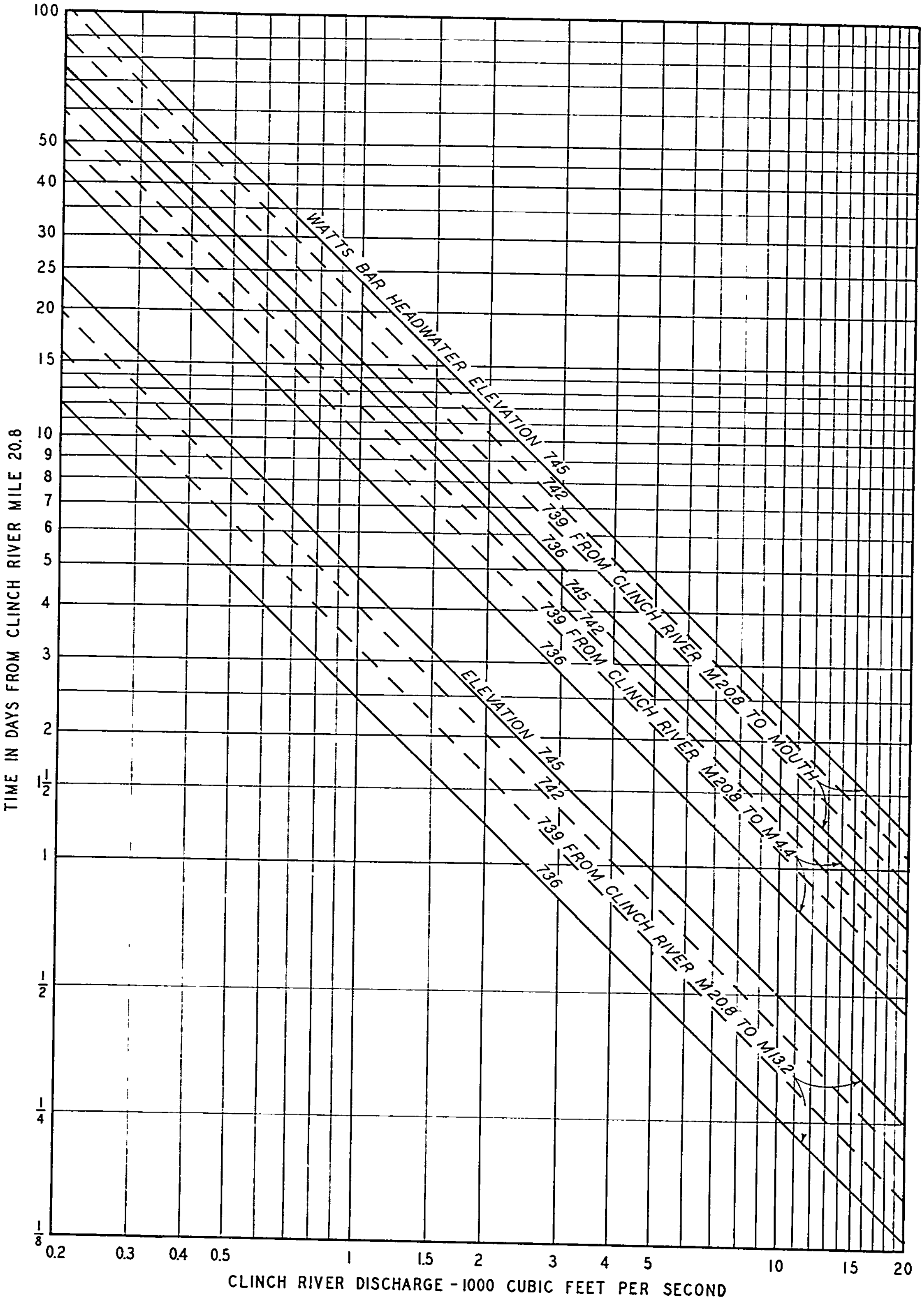
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

AEC SPILLAGE STUDY

LOCATION MAP

OCTOBER 6, 1952

ASF 1256



In general non-stratified flow occurs during the period October through April.

TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

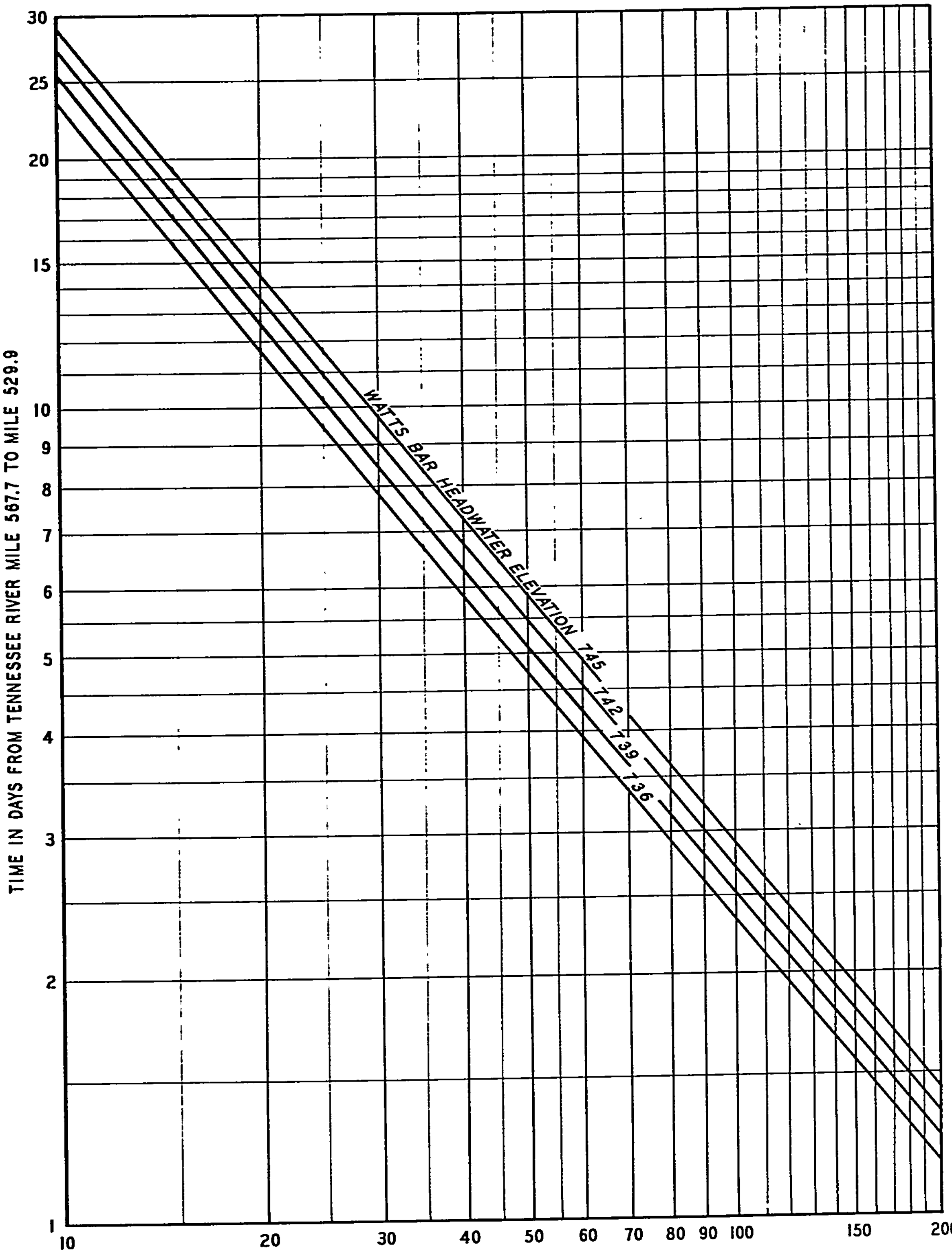
CLINCH RIVER

TIME OF WATER TRAVEL

MILE 20.8 TO MOUTH

NON-STRATIFIED FLOW

OCTOBER 6, 1952



TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

In general non-stratified flow occurs during the period October through April.

WATTS BAR RESERVOIR

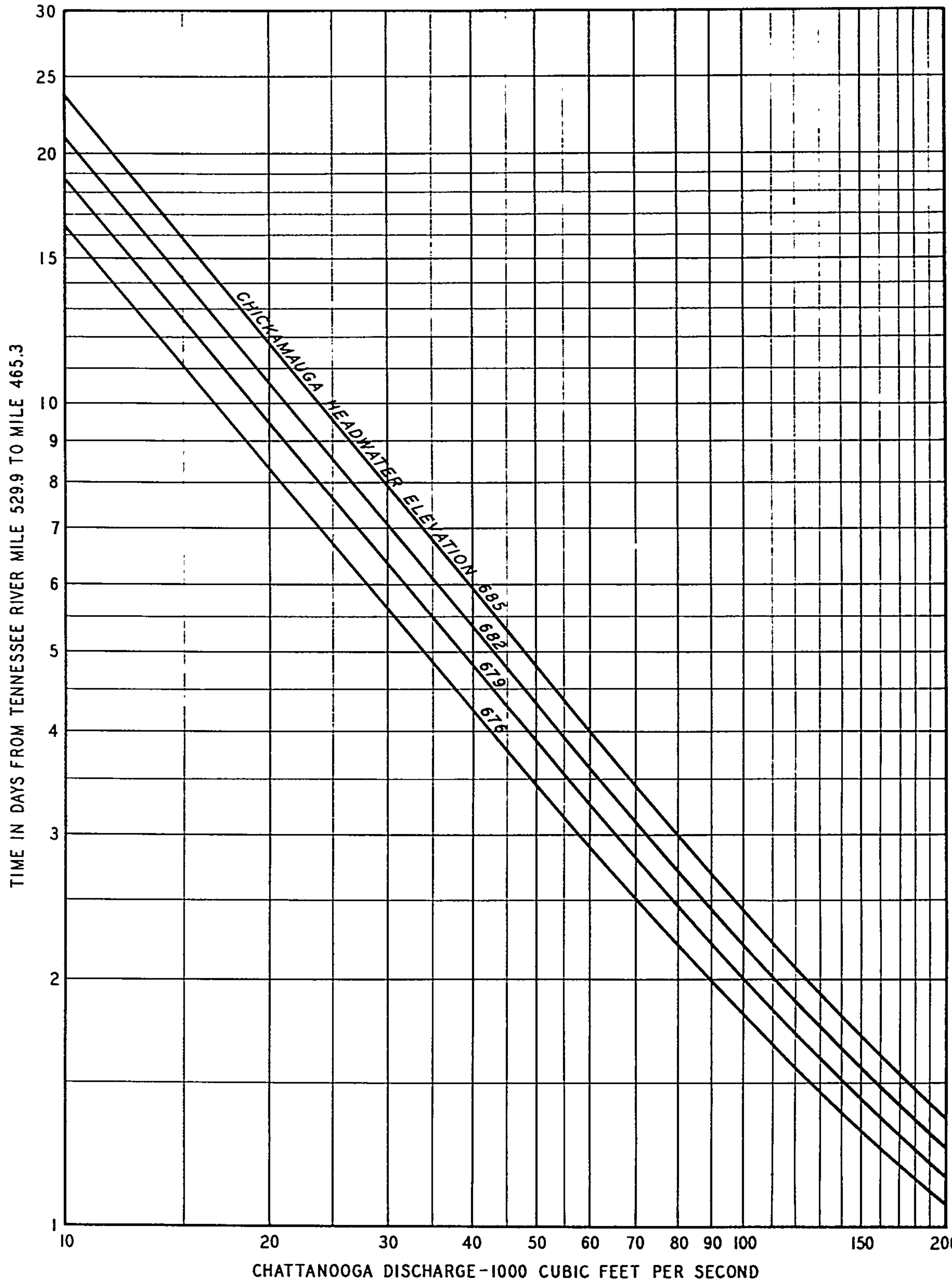
TIME OF WATER TRAVEL

MILE 567.7 TO 529.9

NON-STRATIFIED FLOW

OCTOBER 6, 1952

ASF 1256



This chart applies throughout the year as stratified flow does not occur in this reach.

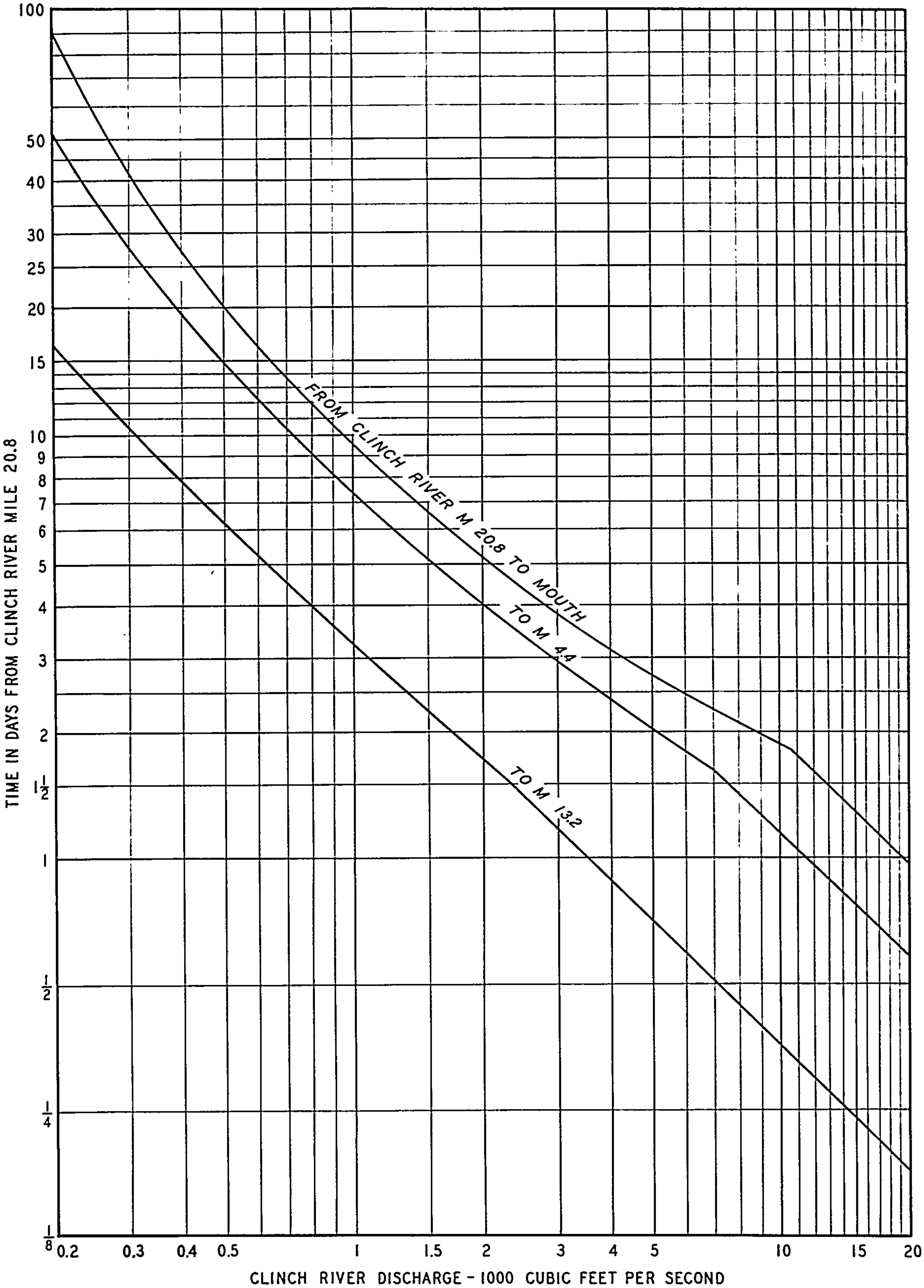
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

TENNESSEE RIVER

TIME OF WATER TRAVEL

MILE 529.9 TO 465.3

OCTOBER 6, 1952

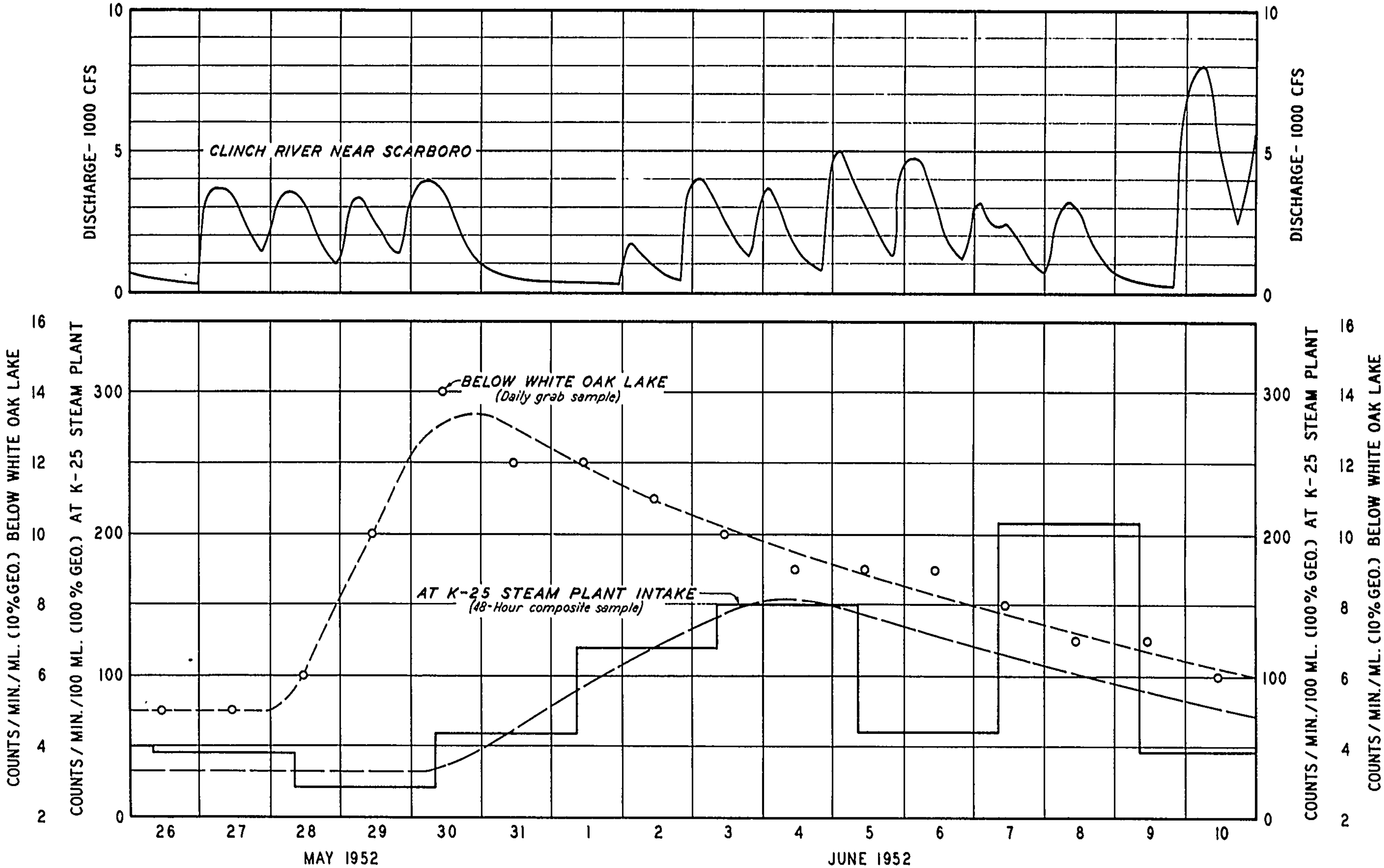


TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

These curves apply for Watts Bar headwater elevation 740 which is about the mean level during the period of stratified flow which normally occurs May through September.

CLINCH RIVER
TIME OF WATER TRAVEL
MILE 20.8 TO MOUTH
STRATIFIED FLOW

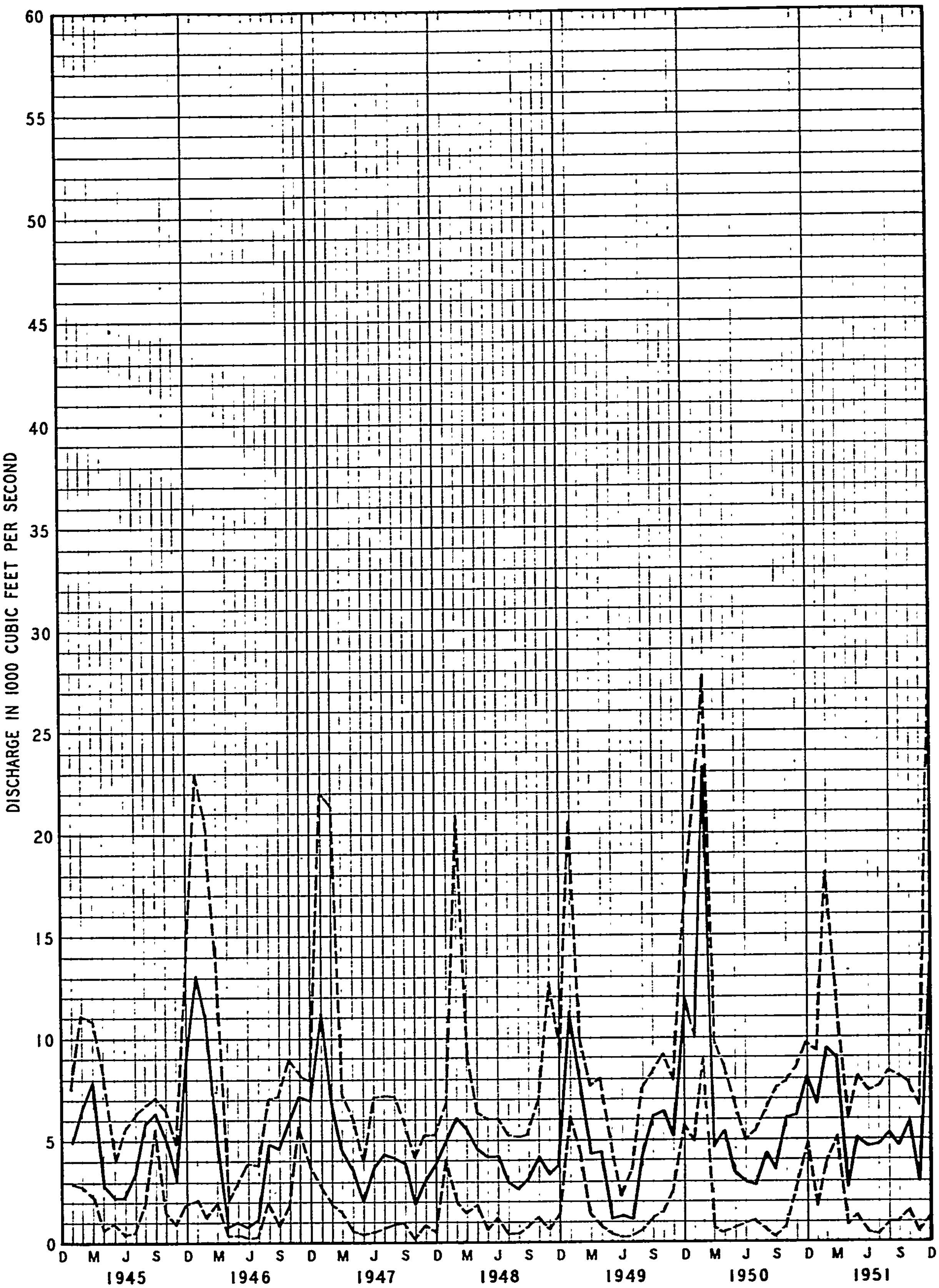
OCTOBER 6, 1952



TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

CLINCH RIVER
OBSERVED TIME OF WATER TRAVEL
MILE 20.8 TO 13.2

OCTOBER 6, 1952



Maxima or minima are maximum, or minimum, values each month for Clinch River near Scarboro. Mean is sum of mean for Clinch River near Scarboro and an estimated local based on drainage area ratios.

TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

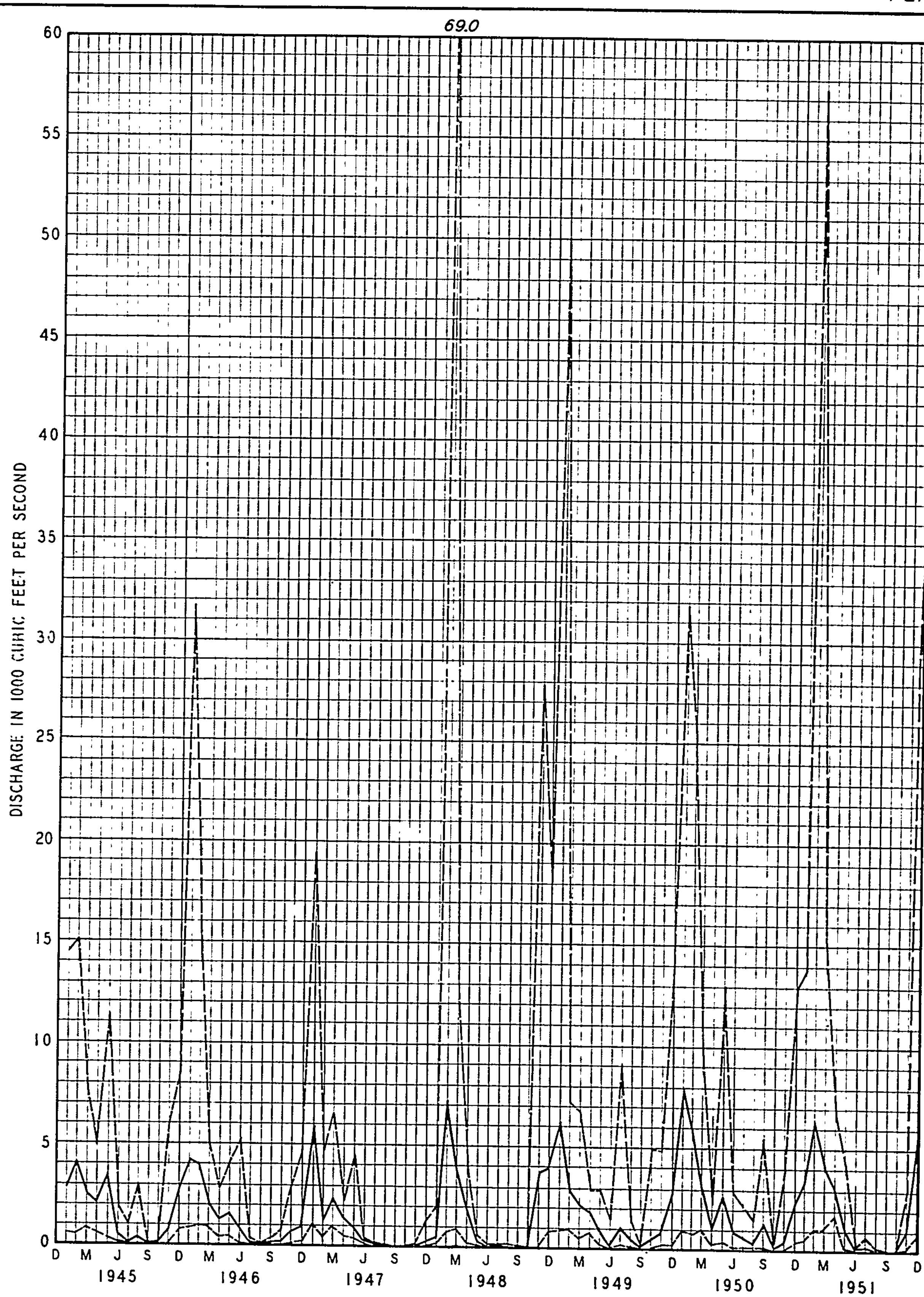
CLINCH RIVER AT MILE 13.2

MAXIMUM, MEAN, AND MINIMUM DAILY DISCHARGES BY MONTHS

1945-1951

OCTOBER 6, 1952

ASF 1256



Maxima or minima are maximum or minimum daily values each month for Emory River at Oakdale. Mean is sum of mean for Emory River at Oakdale and an estimated local based on drainage area ratios.

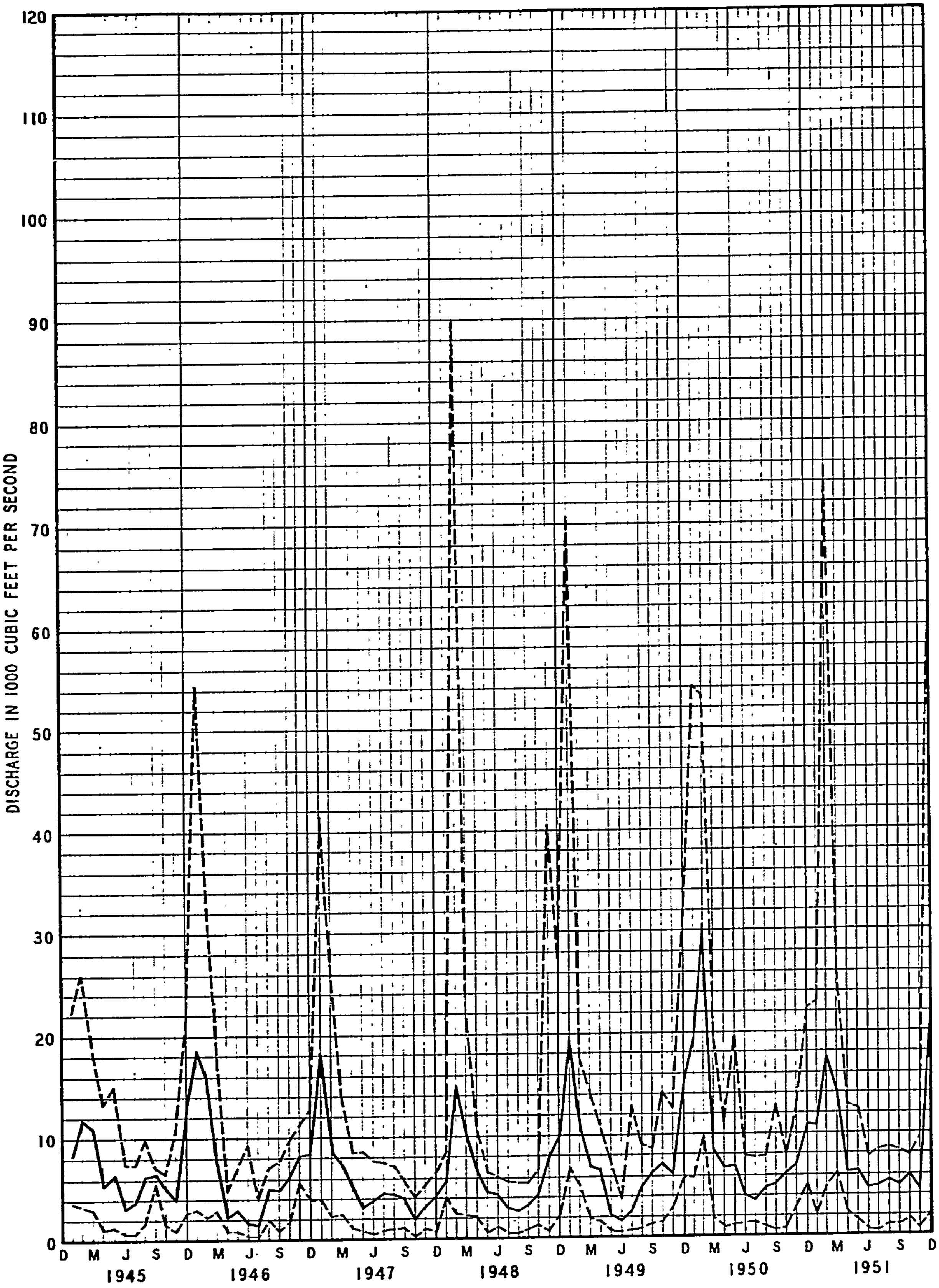
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

EMORY RIVER AT MILE 12.8

MAXIMUM, MEAN, AND MINIMUM DAILY DISCHARGES BY MONTHS

1945-1951

OCTOBER 6, 1952



Maxima or minima are sum of daily maximum or minimum values each month for Clinch River near Scarboro and Emory River at Oakdale. Mean is sum of mean for Clinch River near Scarboro, Emory at Oakdale, and an estimated local based on drainage area ratios.

OCTOBER 6, 1952

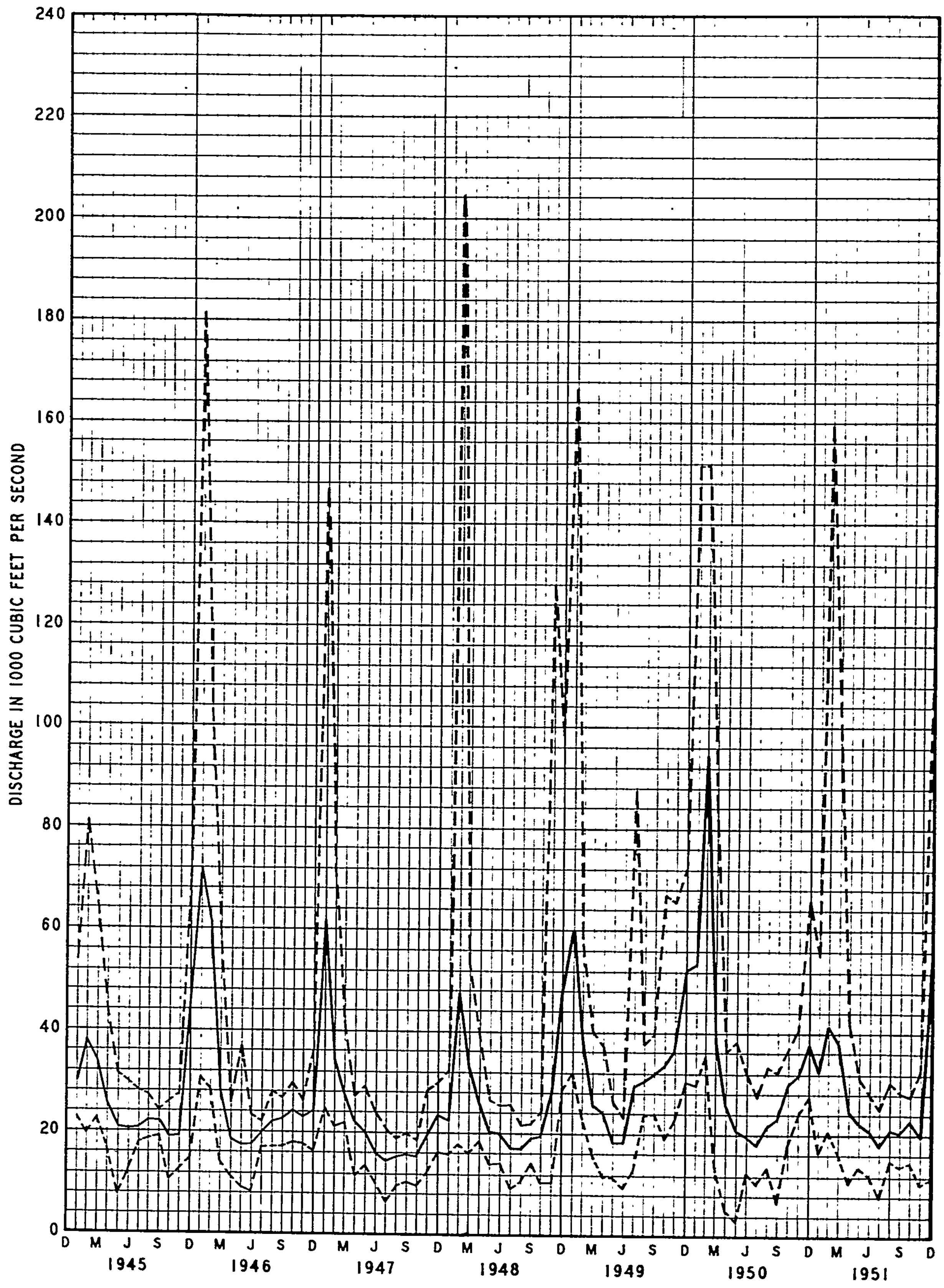
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

CLINCH RIVER AT MILE 4.4

MAXIMUM, MEAN, AND MINIMUM DAILY DISCHARGES BY MONTHS

1945-1951

A5F 1258



TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

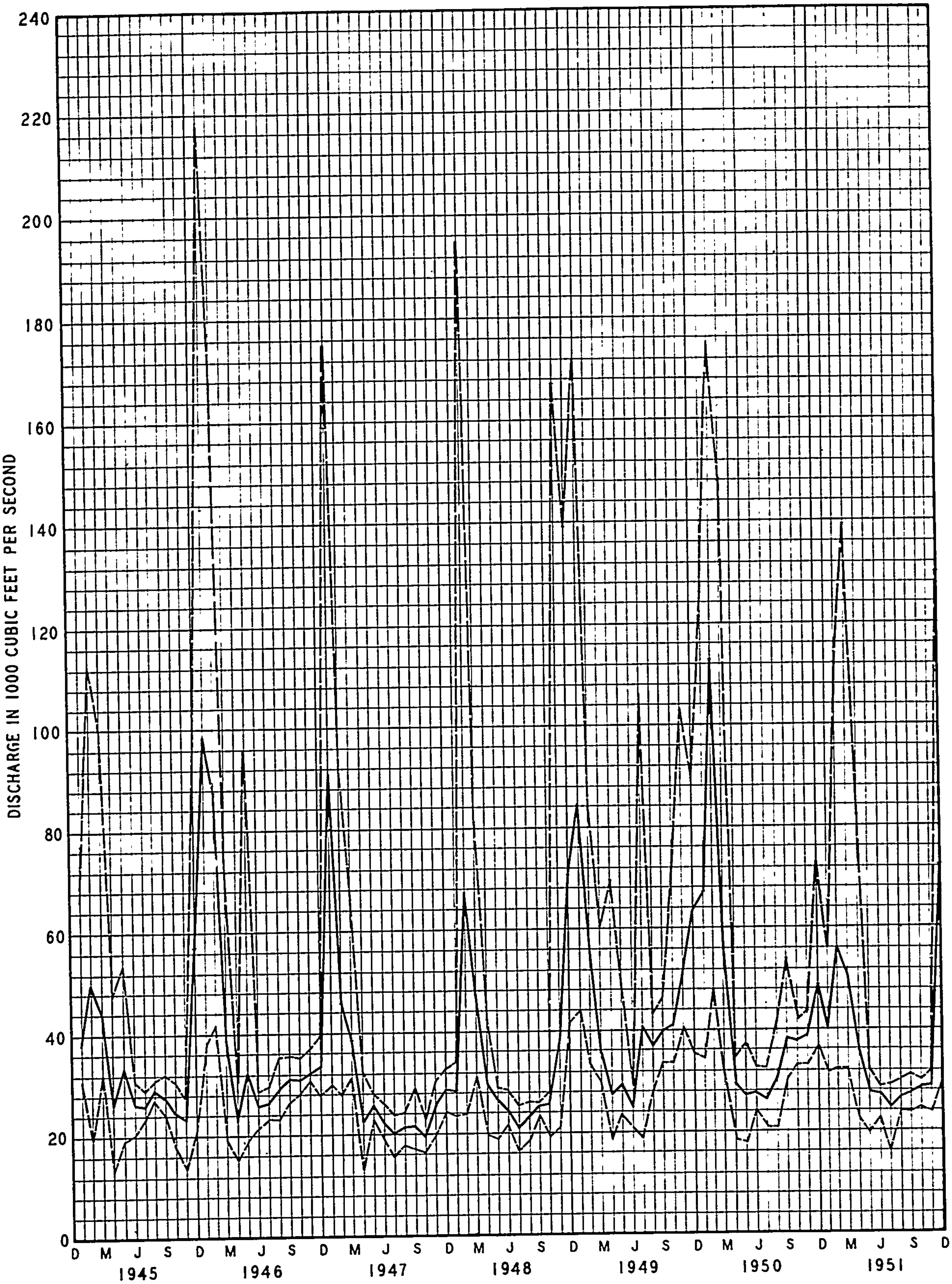
Maxima, means, or minima are maximum, mean, or minimum daily values each month of Watts Bar Reservoir computed inflows.

WATTS BAR RESERVOIR

MAXIMUM, MEAN, AND MINIMUM DAILY INFLOWS BY MONTHS

1945-1951

OCTOBER 6, 1952



TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

Maxima, means, and minima are daily values each month for the Tennessee River at Chattanooga taken from U.S. Geological Survey data.

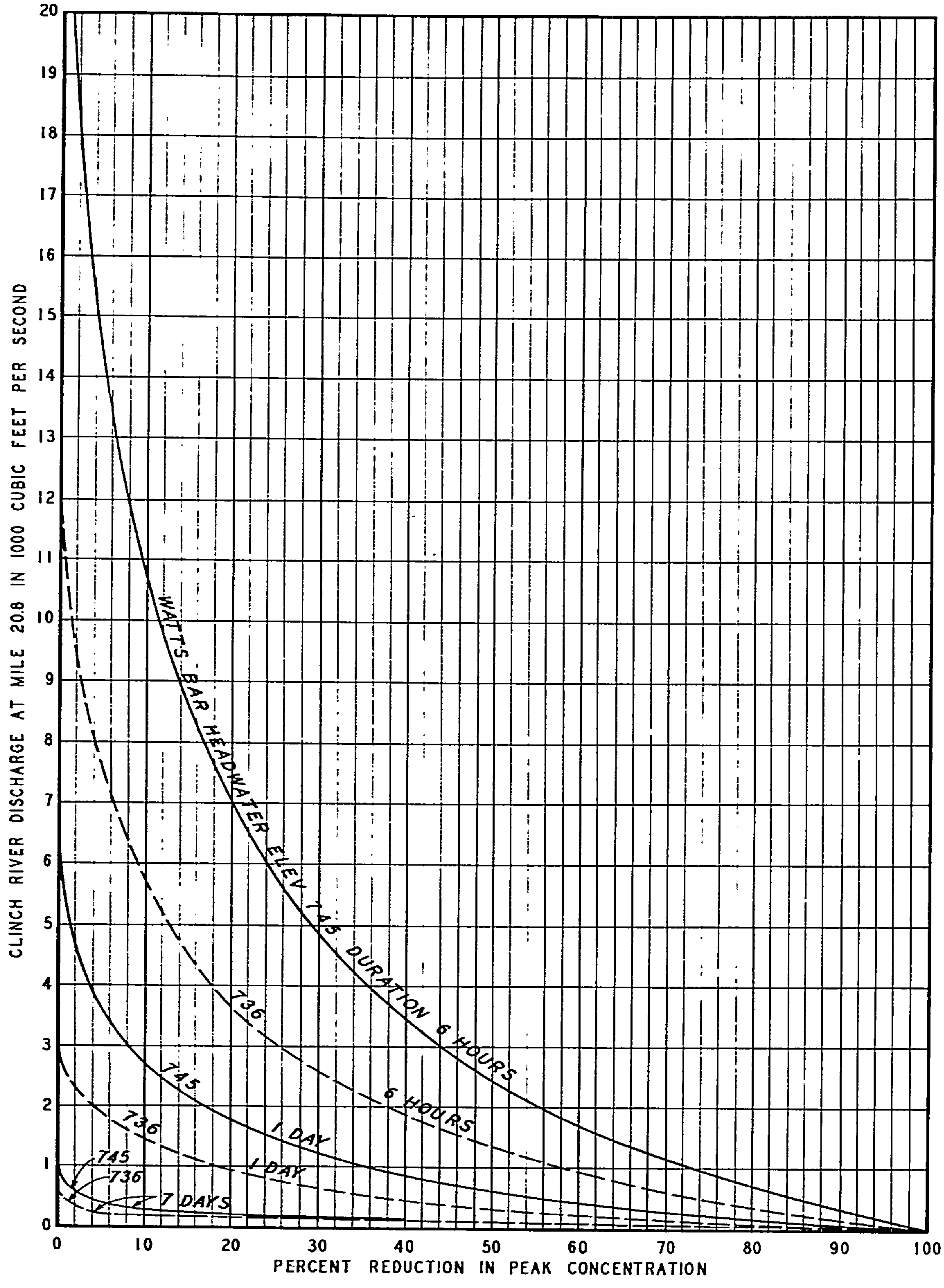
TENNESSEE RIVER AT CHATTANOOGA

MAXIMUM, MEAN, AND MINIMUM DAILY DISCHARGE BY MONTHS

1945-1951

OCTOBER 6, 1952

A-F 1258



Durations indicate period of uniform rate of discharge of wastes at Clinch River mile 20.8. Mixing at this point is assumed. In general non-stratified flow occurs during the period October through April.

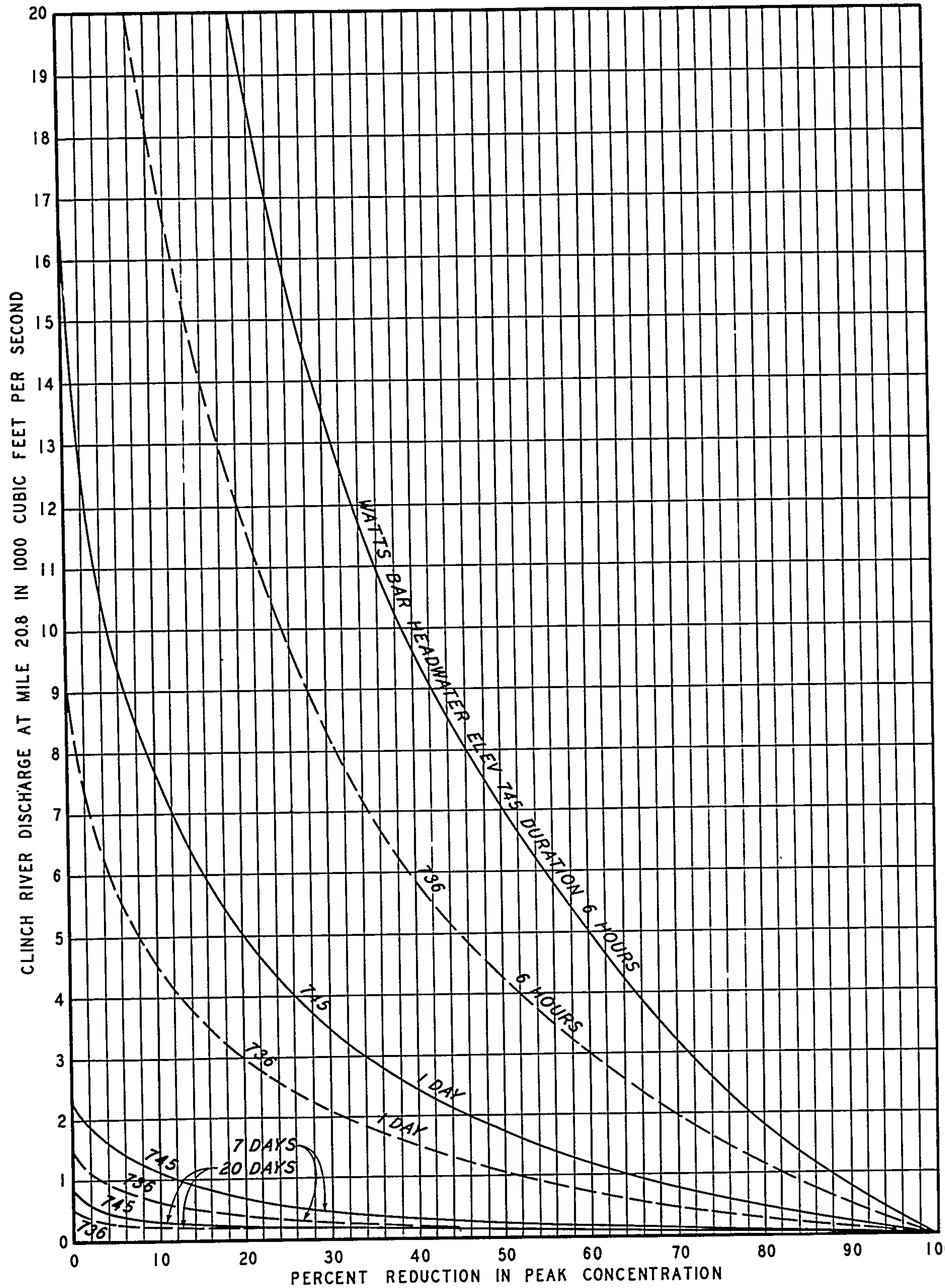
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

CLINCH RIVER

REDUCTION IN PEAK CONCENTRATION DUE TO DISPERSION

MILE 20.8 TO 13.2
NON-STRATIFIED FLOW

OCTOBER 6, 1952



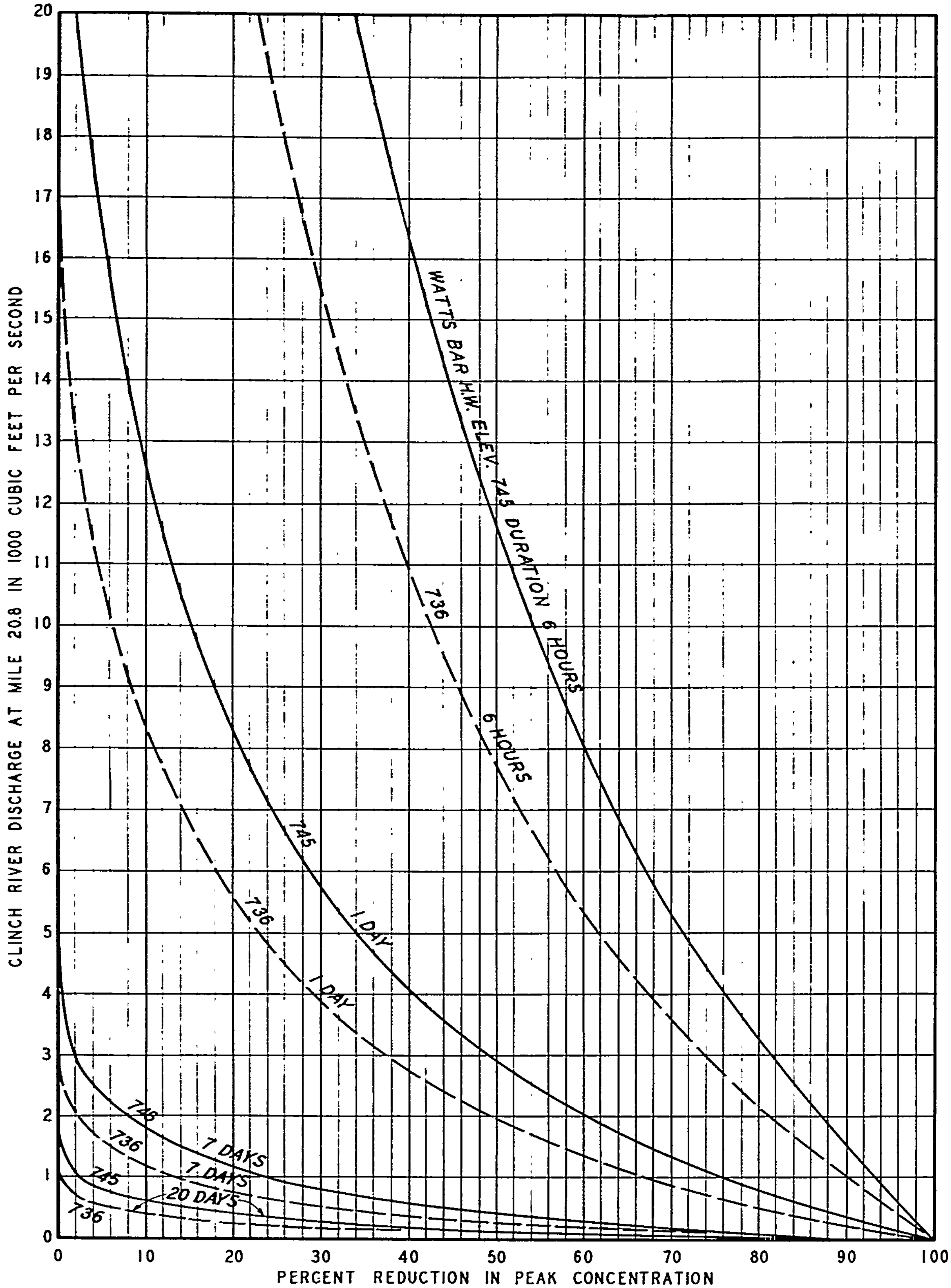
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

Durations indicate period of uniform rate of discharge of wastes at Clinch River mile 20.8. Mixing at this point is assumed. In general non-stratified flow occurs during the period October through April.

CLINCH RIVER
REDUCTION IN PEAK CONCENTRATION DUE TO DISPERSION
MILE 20.8 TO 4.4
NON-STRATIFIED FLOW

OCTOBER 6, 1952

- 1256

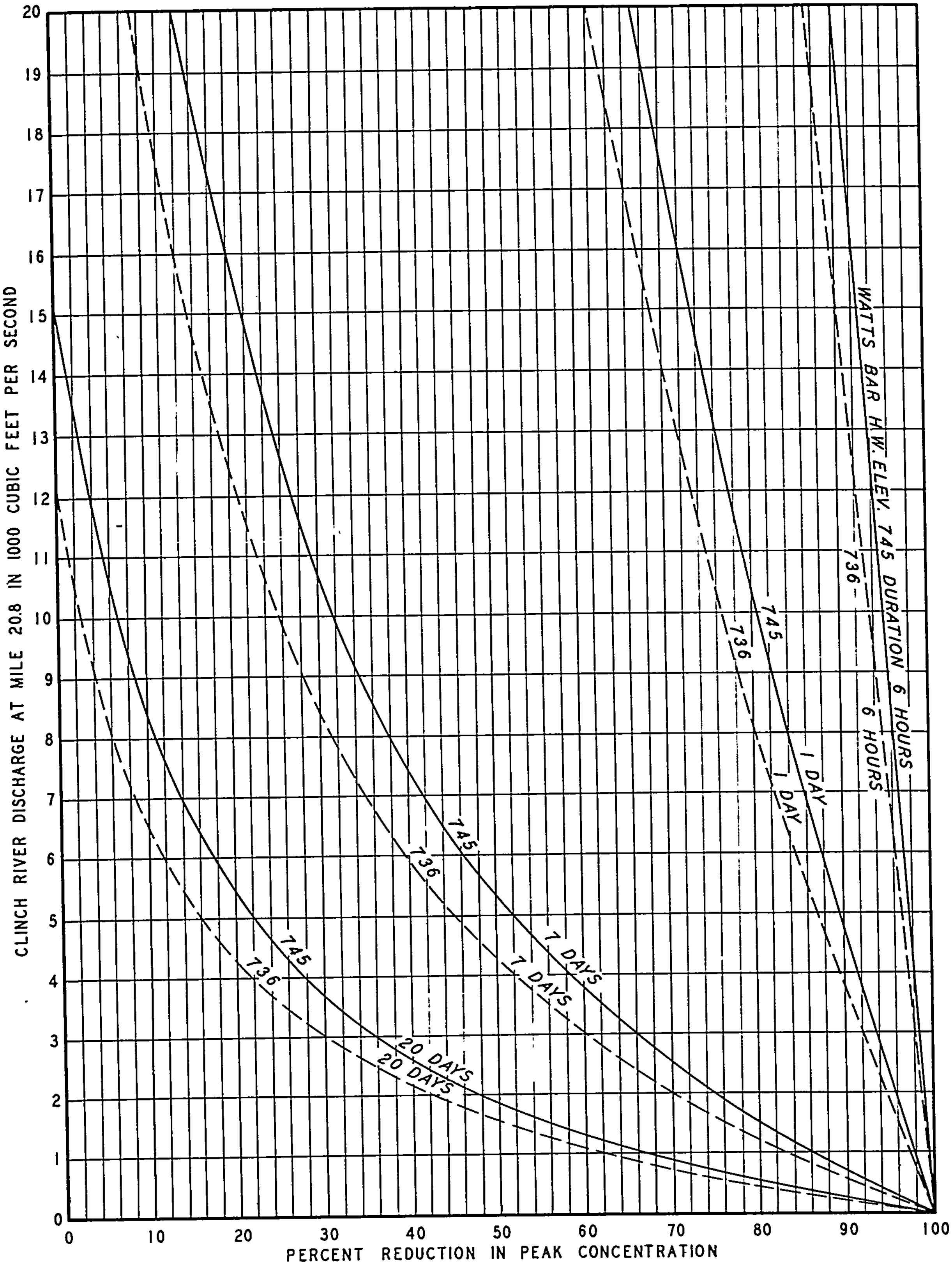


TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

CLINCH RIVER
REDUCTION IN PEAK CONCENTRATION DUE TO DISPERSION
MILE 20.8 TO MOUTH
NON-STRATIFIED FLOW

Durations indicate period of uniform rate of discharge of wastes at Clinch River mile 20.8. Mixing at this point is assumed. In general non-stratified flow occurs during the period October through April.

OCTOBER 6, 1952

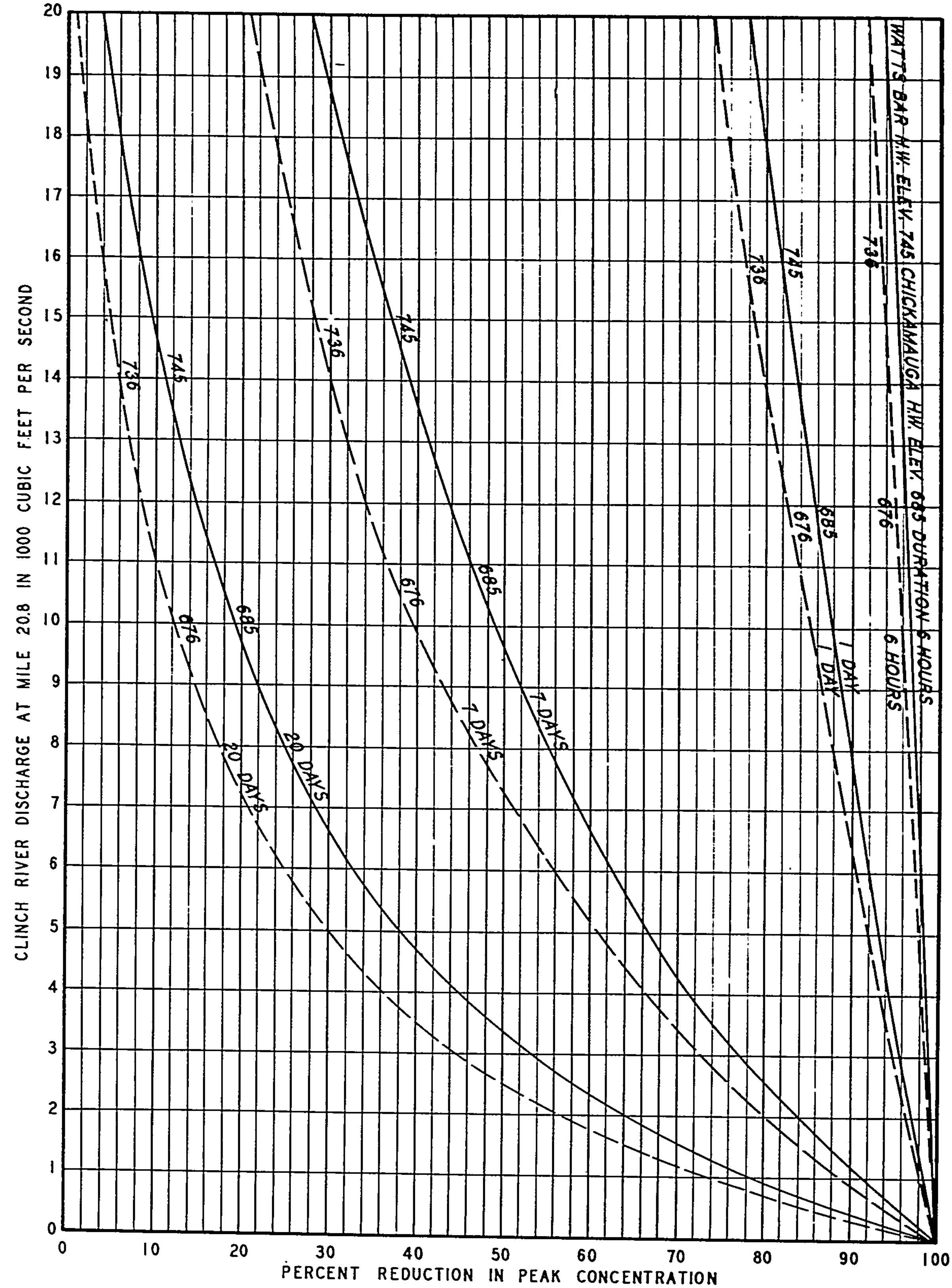


TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

TENNESSEE RIVER
REDUCTION IN PEAK CONCENTRATION DUE TO DISPERSION
MILE CL-20.8 TO MILE TE-529.9
NON-STRATIFIED FLOW

Durations indicate period of uniform rate of discharge of wastes at Clinch River mile 20.8. Mixing at this point is assumed. In general non-stratified flow occurs during the period October through April.

OCTOBER 6, 1952



TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

Durations indicate period of uniform rate of discharge of wastes at Clinch River mile 20.8. Mixing at this point is assumed. In general non-stratified flow occurs during the period October through April.

OCTOBER 6, 1952

TENNESSEE RIVER
REDUCTION IN PEAK CONCENTRATION DUE TO DISPERSION
MILE CL-20.8 TO MILE TE-465.3
NON-STRATIFIED FLOW

Tennessee Valley Authority
Division of Water Control Planning
Hydraulic Data Branch

Water Quality & Ecology Branch File
248 401 Building, C

EFFECT OF ACCIDENTAL SPILLAGE OF RADIOACTIVE WASTE INTO CLINCH RIVER

Report No. 2

WATER CONTROL POSSIBILITIES AND THEIR RESULTS

Knoxville, Tennessee
April 20, 1953

Tennessee Valley Authority
Division of Water Control Planning
Hydraulic Data Branch

EFFECT OF ACCIDENTAL SPILLAGE OF RADIOACTIVE WASTE INTO CLINCH RIVER

Report No. 2

WATER CONTROL POSSIBILITIES AND THEIR RESULTS

In studying the potential hazard that might result from the release of radioactive contamination into Clinch River in the vicinity of the Oak Ridge National Laboratory, data are needed on water control operations that might be used to retard the passage of the contamination through TVA reservoirs, thereby aiding in reducing its effect. Since the reservoirs are operated by TVA, these data can be supplied only by TVA.

Report No. 1 issued November 10, 1952, discussed time of travel, probable flows, and dispersion. This report gives the results of the remaining portion of investigations made to supply information requested by Dr. Karl Z. Morgan, Director of the Health Physics Division, AEC, in his letter of January 29, 1952, to Dr. O. M. Derryberry, Director of Health, TVA, and covers the part of item 3 relating to duration of concentration and the last four items stated in the letter. These last four items are:

4. By control of flow from Norris Dam and of water level in Watts Bar Reservoir, how long would it be possible to prevent contamination from getting as far downstream as Clinch River miles 13.2 and 4.4, Emory River mile 12.8, and Tennessee River mile 567.7 under seasonal conditions of side drainage for the different seasons?

5. When it becomes no longer possible to retain all of the contaminant in the Clinch River embayment, can the flow be regulated in such a manner as to discharge to the Tennessee River very small quantities of contaminant, in other words, let it "dribble" out?

6. In the case of (5), how long after release at Clinch River mile 20.8 would the first contamination reach Emory River mile 12.8, Tennessee River miles 529.9 and 465.3?

7. What would be the reduction in peak concentrations and the duration of concentration under these conditions of controlled release?

The answers which are given to these last four items are based upon the physical possibilities of enacting the water control measures which are needed to accomplish the retardation desired. Such measures may conflict with the best water control operations for other purposes. For this reason, these control measures should be considered only as operations that are physically necessary to give desired results.

Plate 1 shows the relative geographical location of the various points under consideration on the Emory, Clinch, and Tennessee Rivers.

Duration of Contamination

Item 3 of Dr. Morgan's letter requested the duration of concentration exceeding one percent of the initial concentration (after mixing at Clinch River mile 20.8) at each point, assuming uniform rate of discharge of wastes at Clinch River over specified periods. None of the measurements of concentrations taken in the various water travel studies are sufficiently refined to determine durations of concentrations exceeding one percent of the initial value. However, it has been possible to devise a method by which the duration of identifiable contamination downstream from the point of release of waste can be computed.

This duration of contamination is dependent upon the period of time over which the waste is released and the average time of water travel from the point of release to the downstream point under consideration. In Report No. 1 the average time of water travel was shown to be dependent upon the magnitude of the flow with which the waste mixes and the elevation of the reservoir into which it is discharged. A formula has been developed by which the duration of contamination can be computed. The derivation of this formula is given in Appendix A accompanying this report. The formula is:

$$x = T_{av} + 1.5\,D$$

in which:

- x = Duration of contamination in days at a point downstream from Clinch River mile 20.8.
- T_{av} = Average time of water travel in days from Clinch River mile 20.8 to the point.
- D = Duration of uniform release of waste in days at Clinch River mile 20.8.

It is apparent from the formula that the determination of the duration of contamination at any of the downstream points only requires adding one and a half times the duration of uniform release of waste at Clinch River mile 20.8 to the average time of water travel to the point. The average time of water travel is determined for a given set of conditions of flow and reservoir elevation from data given in Report No. 1: Plates 2, 3, and 4 for non-stratified flow conditions or Plate 5 and page 8 for stratified flow conditions.

Possible Retardation of Contaminant in Clinch River Embayment

It may be desirable to retard the passage through the Clinch River embayment of the contamination accidentally released at mile 20.8 in order to lengthen the time available for natural decay.

If the contamination does not get into a stratum of cold Norris water, this retardation can be accomplished by raising the water level of Watts Bar Reservoir fast enough to delay the passage of the contaminant to the downstream point which is to be protected. This filling would result in storing temporarily in the reach upstream from this point the Clinch River flow containing the contamination. The amount of filling in Watts Bar Reservoir will be dependent upon the flows released from upstream reservoirs and the reduction in discharge at Watts Bar Dam. It is possible, under certain conditions, that flows of the necessary magnitude would not be available without completely upsetting the established reservoir system operating plan as well as curtailing some power generating facilities.

Should an accidental spillage occur during the stratified flow period and the waste get into an existing stratum of cold Norris water, it would be impossible to hold the contamination in the Clinch River embayment. At best, it would only be possible to keep the contamination in the lower portions of Watts Bar Reservoir by shutting down the turbines. This operation would prevent drawing out the cold Norris stratum containing the contamination which flows along the bottom. Any withdrawal of water from Watts Bar Reservoir would have to be done by discharging over the spillways. This spillage would have to be at a rate which would not produce velocities in Watts Bar Reservoir of sufficient magnitude to pick up any of the contaminated water stratified on the bottom.

A decision will have to be made [redacted] whether maximum retardation is desired for Clinch River mile 13.2, 4.4, or Tennessee River mile 567.7. The retarding operation would then be carried out to obtain the maximum benefit for the point chosen. To accomplish this retardation beyond that due to ordinary time of water travel it is desirable that certain measures be undertaken after the accidental spillage:

1. Norris Dam discharge should be reduced immediately to an absolute minimum, preferably zero. However, consideration should be given whether this low release is desirable from the standpoint of the water intake for Oak Ridge and Y-12 water supply.

2. Filling Watts Bar Reservoir should begin as soon as an increase in pollution is detected at White Oak dam. The rate of filling should be such as to store water in the Clinch River embayment upstream from the point to be protected at one and one-half times[1] the rate of the Clinch River flow at the point.

The rate of local inflow between Norris Dam and the point of interest can be estimated currently by expanding, on a drainage area ratio, the difference between the flow of the Clinch River at Scarboro and the flow

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1. The first contamination travels at a velocity which is about one and one-half times the average velocity.

below Norris Dam 12 hours earlier. Table 3 on page 10 gives these drainage area ratios needed to estimate the Clinch River local inflow on this basis.

Plate 17 shows the time required for the first contamination to move from Clinch River mile 20.8 to 13.2 for a given initial Watts Bar headwater elevation, the average Clinch River flow in the reach, and a permissible rise in reservoir level. Similarly, Plate 18 shows the time of travel to Clinch River mile 4.4. Plate 19 shows the time of travel to the mouth of the Clinch River at Tennessee River mile 567.7, taking account of the effect of flow in Emory River.

If it is desired to effect the maximum retardation to mile 13.2, the period of filling of Watts Bar Reservoir must be equal to the time required for the first contamination to travel to mile 13.2 determined from Plate 17. To effect the maximum retardation to either mile 4.4 or the mouth of the Clinch River, the period of filling must be equal to the time of travel to mile 4.4 determined from Plate 18 or to mile 0.0 from Plate 19.

Between May and September stratified flow conditions are normally induced in the Clinch River embayment of Watts Bar Reservoir. However, if no cold Norris water is released, there will be no tendency to form a stratum in which the contamination would be carried. Therefore, the curves of Plates 17, 18, and 19 of this report will serve for year-round flow conditions when a retarding operation is being performed, assuming the contamination does not get into a stratum of cold Norris release.

Table 4 on page 11 shows the retarding effect accomplished at Clinch River mile 13.2 when operating to obtain the maximum effect at mile 4.4 or the mouth. It is apparent from this tabulation that very little retarding effect is accomplished at mile 13.2 if the retarding operation is performed principally for Clinch River mile 4.4 or the mouth.

Effect of Operation on Norris Reservoir

If Norris Reservoir is at or above the level which provides the storage space reserved for flood control at the beginning of a retarding operation, it may be necessary to infringe upon that space to store the entire inflow. Furthermore, any limitation on Norris discharge would result in reduction of power generation. All median inflow into Norris

Reservoir could be stored for a month by utilizing as much as 25 percent of the reserved flood control space in winter and 50 percent in summer.

Effect of Operation at Emory River Mile 12.8

If there is only little or no discharge from Norris Dam, the retarding operation would prevent contamination from being pushed up the Emory River as far as the Harriman water plant intake at mile 12.8. This action would be due primarily to this lack of a cold water stratum which is necessary during the stratified flow period to transport the contamination up the Emory River embayment when the Emory River flow is low (less than about 500 cubic feet per second).

Furthermore, the method of performing the retardation requires that the rate of filling of Watts Bar Reservoir be determined by the rate of the Clinch River flow above the point to be protected. This has the effect of blocking contaminants from reaching the mouth of the Emory River for relatively long periods compared to normal time of travel.

Probable Local Inflows

Table 5 on page 12 gives the mean daily local inflows by months which occurred in the period 1941 to 1951 between Norris Dam and each point under consideration on the Clinch River as well as the mean daily flows for the Emory River at its mouth during this same period.

Release of Contamination out of Clinch River Embayment

As the retarding operation by filling progresses, it will become impossible, in time, to retain all of the contamination in the Clinch River embayment by reason of filling Watts Bar Reservoir to the maximum permissible level, filling Norris Reservoir to excessive levels, or an increase in flow from the uncontrolled Emory River and the local area below Norris Dam. Whether very small quantities of contamination can be "dribbled" out into the Tennessee River will depend upon these flow conditions and how long Watts Bar Reservoir can be maintained above normal levels - a highly undesirable condition for flood control. The various factors of weather, runoff conditions, flood control reservations, and power requirements are complex and interrelated. An answer based upon any selected group of these factors would be of little value, because the occurrence of such a combination is too problematical. However, with favorable weather conditions prevailing, it would be possible to spread the discharge of Clinch River water containing contamination into the Tennessee River by limiting releases from Norris Dam and the rate of drawdown of Watts Bar Reservoir.

Time Required for Contaminant to Move Downstream

After release at Clinch River mile 20.8 the time required for the first contamination to reach Emory River mile 12.8, and Tennessee River miles 529.9 and 465.3 will depend upon the existing rates of flow in the Emory, Clinch, and Tennessee Rivers.

As long as the rate of flow from Norris Dam is kept below 3000 cubic feet per second or not maintained at or above this rate for more than a few days the Clinch River water containing the contamination will not reach Emory River mile 12.8.

The time required for the contaminant to move from the mouth of the Clinch River at Tennessee River mile 567.7 to Tennessee River miles 529.9 and 465.3 can be estimated for various flow and reservoir conditions from data given in Report No. 1: Plates 3 for Watts Bar Reservoir during the non-stratified flow period and pages 7 and 8 during the stratified flow period; Plate 4 for Chickamauga Reservoir which is applicable to year-round conditions.

Reduction in Peak Concentration

A retarding operation will produce, in addition to slowing up the passage of contaminant, reductions in the peak concentration due to the more complete dispersion than would occur with a steady initial pool. The raising of Watts Bar Reservoir to a higher level will have practically the same effect as though the reservoir was at a steady level equivalent to the average of the initial lower level and the final higher level to which the reservoir is raised. A larger reduction in peak concentration due to dispersion also results from reducing the flow in the Clinch River, thereby permitting more time for the dispersion of the contaminant into small embayments than possible with larger flows which produce faster times of water travel. The reduction due to dispersion in the Clinch River during the retarding operation can be determined for any season of the year by using the curves on Plates 12, 13, and 14 of Report No. 1. The only modification needed in applying these curves is to use the average of the initial reservoir level and the final level to which it is raised.

The additional reduction in peak concentration due to dilution is determined from the total flows available at each point, as in Report No. 1. The total reduction is equal to the products of the concentration remaining at the point (after dispersion and dilution) subtracted from unity.

Duration of Contamination with Controlled Releases

The duration of contamination at any downstream point under conditions of controlled release may be determined by the method used for steady reservoir conditions. However, it must be noted that the time of water travel determined from Plate 17, 18, or 19 of this report is the time required for the first contamination to move from Clinch River mile 20.8 to the downstream Clinch River point. The formula given on page 3 adjusted to utilize this minimum time of travel is:

$$x = 1.5\,(T_{min} + D)$$

in which:

- x = Duration of contamination in days at the point downstream from Clinch River mile 20.8.
- T_{min} = Time of water travel in days for first contamination to move from Clinch River mile 20.8 to the point downstream.
- D = Duration of uniform release of waste in days at Clinch River mile 20.8.

Comparison of Results of Normal Operation and Retarding Operation

In Table 6 shown on page 13 a summary has been made of the computations in the illustrative examples given in Report No. 1 and in this Report No. 2 for the purpose of comparing the effect of the retarding operation with normal operation.

ACKNOWLEDGMENTS

This report was prepared under the general direction of Albert S. Fry, Chief, Hydraulic Data Branch, by the Procedures Development Section under the immediate direction of Alfred J. Cooper, Head, who prepared the report. Archie W. Diegel was responsible for the analyses of data and computations. Acknowledgment of technical assistance is made to J. H. Wilkinson, Staff Assistant.

Tennessee Valley Authority
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Hydraulic Data Branch

TABLE 3

Drainage Area Ratios

Clinch River Below Norris Dam

Drainage Area from Norris Dam to	Ratio of Area to Scarboro less Norris
Clinch Mile 20.8 (above White Oak Creek)	1.121
Clinch Mile 13.2 (K-25 Steam Plant Intake)	1.224
Clinch Mile 4.4 (excluding Emory River)	1.621
Mouth of Clinch (excluding Emory River)	1.639

Drainage Area At	Ratio of Area to Emory River at Oakdale
Emory Mile 12.8 (Harriman water plant)	1.045
Mouth of Emory River	1.132

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TABLE 4

Retardation in Days to Clinch River Mile 13.2
While Filling for Maximum Effect at Mile 4.4 or Mouth

(for Clinch River Flow of 1000 Cubic Feet Per Second)

Watts Bar Reservoir Elevation	Fill in Watts Bar Reservoir - Feet					
	0	2	4	6	8	10
735	1.4	1.5	1.6	1.7	1.7	1.8
737	1.8	1.9	2.0	2.1	2.2	-
739	2.1	2.3	2.5	2.6	-	-
741	2.5	2.8	3.0	-	-	-
743	2.9	3.2	-	-	-	-

For Clinch River flows other than 1000 cubic feet per second retardation is inversely proportional to flow.

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TABLE 5

Mean Daily Local Inflows in Cubic Feet Per Second

Clinch River Below Norris Dam
1941-1951

	CLINCH RIVER			EMORY RIVER
	At Mile 20.8	At Mile 13.2	At Mile 4.4 & 0[a]	At Mouth
Month	Mean	Mean	Mean	Mean
Jan.	1290	1410	1870	3600
Feb.	1810	1980	2630	4270
Mar.	1280	1390	1860	3330
Apr.	790	860	1140	2090
May	500	540	720	1310
Jun.	210	230	300	330
Jul.	330	360	480	520
Aug.	260	290	380	360
Sep.	330	360	480	340
Oct.	210	230	300	120
Nov.	480	530	700	910
Dec.	980	1070	1420	2850

a. Flows shown at Clinch River miles 4.4 and 0 (Tennessee River mile 567.7) do not include Emory River flows.

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TABLE 6

Comparison of Results
of Normal Operation with Retarding Operation
(From Illustrative Examples Using March Mean Discharge Data)

	Clinch River Mile					
	13.2		4.4		Mouth	
	Normal	Retarded	Normal	Retarded	Normal	Retarded
Time of Travel in days[1]	0.3	3.4	1.0	7.3	1.5	8.3
% Reduction in Peak Conc.[2]	0	26	41	88	50	92
Duration of Contamination in days	2.0	6.6	3.0	12.5	3.8	14.0

1. For first contaminant = 2/3 average time of water travel.
2. Due to dispersion and dilution.

APPENDICES

Accompanying are two appendices. Appendix A gives the original derivation of the formula for computing duration of contamination. Appendix B is a sample computation illustrating the use of the plates accompanying this report.

APPENDIX A

DERIVATION OF FORMULA

FOR

COMPUTING DURATION OF CONTAMINATION

The diagram below shows the time-contamination graphs at the initial Point 1 (Clinch River mile 20.8) and at some Point 2 downstream. The symbols thereon have the following significance:

D = Duration of uniform release of waste

c.g. = Centroid of distribution

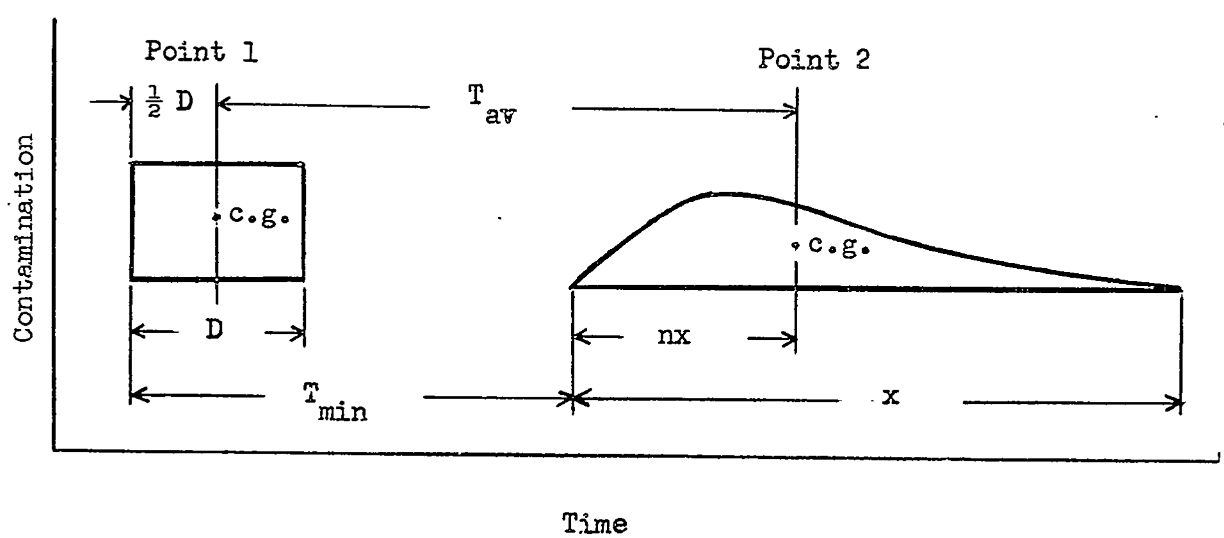
T_{av} = Average time of water travel between Point 1 and Point 2 and is time between centroids

T_{min} = Time of water travel for first contamination to arrive at Point 2

x = Duration of contamination at Point 2

nx = Time from arrival of first contamination at Point 2 to centroid of distribution at Point 2

n = Ratio of nx to x



From the diagram the following equality is apparent:

$$nx = T_{av} + 1/2\ D - T_{min}$$

$$\text{or } x = 1/n\ (T_{av} + 1/2\ D - T_{min}) \qquad (1)$$

Observations of velocity distribution in a cross-section of a reservoir show that the maximum velocity V_{max} is about one and a half times the average velocity V_{av}[2]:

$$V_{max} = 3/2\ V_{av}$$

When the velocity is a maximum, the time of water travel is a minimum so:

$$T_{min} = 2/3\ T_{av}$$

Substituting in (1)

$$x = 1/n\ (1/3\ T_{av} + 1/2\ D) \qquad (2)$$

A study of the duration of contamination data obtained in the White Oak Lake water movement investigations in 1950 and 1951, in the Holston River above and below Cherokee Reservoir, and in Fort Loudoun Reservoir showed that the value of n varied between 1/2.6 to 1/3.5 so adopting a mean value for n of 1/3, formula (2) reduces to:

$$x = 3\ (1/3\ T_{av} + 1/2\ D)$$

$$\text{or } x = T_{av} + 1.5\ D \qquad (3)$$

---

2. These field data verify the theoretically obtainable 3/2 ratio of maximum velocity to average velocity assuming parabolic variation in a cross-section of velocity with depth.

APPENDIX B

ILLUSTRATIVE EXAMPLE OF USE OF BASIC CURVES

Given: March mean discharge data (taken from Table 5).

Assume release from Norris Dam has been reduced to zero soon enough so that only the local inflow is in the Clinch River.

Discharges at:	Clinch River mile 20.8	1,280 cfs
	Clinch River mile 13.2	1,390 cfs
	Clinch River mile 4.4 (without Emory River)	1,860 cfs
	Emory River at mouth	3,330 cfs

Watts Bar Headwater (initially)	El. 736
Permissible fill in Watts Bar Reservoir	8 feet
Chickamauga Headwater	El. 676
Duration of Waste spillage	1 day

Desired: (1) Length of time contamination can be kept above Clinch River miles 13.2 and 4.4, and Tennessee River mile 567.7 to obtain the maximum retardation to each point with a permissible fill of 8 feet in Watts Bar Reservoir.

(2) Length of time it would take for first contaminant to reach Clinch River mile 13.2 if retarding operation was performed for maximum effect at Clinch River mile 4.4.

(3) Reduction in peak concentration due to dispersion and dilution only and the duration of contamination at each point.

A. Retardation

From Clinch River mile 20.8 to 13.2

With Norris Dam release reduced to zero the average flow between Clinch River miles 20.8 and 13.2 is taken as the average of the discharge at Clinch River mile 20.8 of 1,280 cubic feet per second and the discharge at mile 13.2 of 1,390 cubic feet per second or 1,340 cubic feet per second.

Enter Plate 17, as shown by dashed line, with the given initial Watts Bar Headwater Elevation 736, go right horizontally to a Clinch River Flow of 1,340 cubic feet per second, interpolating between the 1000 and 1500 cfs lines, thence vertically up to the line for Filling Watts Bar Reservoir 8 feet and project horizontally to the left, reading the Time in Days from Clinch River mile 20.8 for the first contaminant to reach mile 13.2.

Time of water travel for first contaminant to reach
Clinch River mile 13.2 = 3.4 days.

This time represents the retardation attainable if filling operation is performed for the maximum effect at mile 13.2. The filling of 8 feet in Watts Bar Reservoir would also have to be done in 3.4 days or at a rate of 2.2 feet per day. This filling would require storing about 42,000 day-second-feet each day.

From Clinch River mile 20.8 to 4.4

The average flow between Clinch River mile 20.8 and 4.4 is taken as the average of the discharge at Clinch River mile 20.8 of 1,280 cubic feet per second and the discharge at mile 4.4 of 1,860 cubic feet per second or 1,570 cubic feet per second.

Enter Plate 18, as shown by dashed line, in the same manner as in the preceding explanation for Plate 17.

Time of water travel for first contaminant to reach
Clinch River mile 4.4 = 7.3 days.

This time represents the retardation attainable if filling operation is performed for the maximum effect at mile 4.4. The filling of 8 feet in Watts Bar Reservoir would also have to be done in these 7.3 days or at a rate of 1.1 feet per day. This filling would require storing about 21,000 day-second-feet each day.

If the filling is performed for maximum effect at Clinch River mile 4.4, the retardation to Clinch River mile 13.2 can be computed from Table 4 as follows:

Under the column for <u>Fill in Watts Bar Reservoir</u> of 8 feet interpolate between <u>Watts Bar Reservoir Elevation</u> 735 and 737 to obtain time of 2.0 days for Elevation 736 with a Clinch River Flow of 1000 cubic feet per second. For a flow of 1,340 cubic feet per second the retardation is inversely proportional to flow.

Retardation in days to Clinch River mile 13.2 while filling for maximum effect at mile 4.4 =

$$\frac{1000}{1340} \times 2.0 = 1.5 \text{ days.}$$

Comparing the 1.5 days with the 3.4 days retardation accomplished by operating for maximum effect at mile 13.2, 1.9 days would be lost by operating for maximum effect at mile 4.4.

According to Table 4 with no fill in Watts Bar Reservoir and a flow of 1,340 cubic feet per second the retardation at Clinch River mile 13.2 is 1.2 days. So, practically no additional retardation is achieved at mile 13.2 by filling for maximum effect at mile 4.4.

<u>From Clinch River mile 20.8 to Mouth of Clinch River</u>

The average flow between Clinch River mile 20.8 and the mouth of the Clinch River (without the Emory River flow) is taken as 1,570 cubic feet per second, the same as the average discharge between Clinch River miles 20.8 and 4.4 computed above since the local drainage area between mile 4.4 and the mouth is small.

Enter Plate 19, as shown by dashed line, in the same manner of the preceding explanations but in addition project horizontally to the left to the intersection with the Emory River Flow of 3,330 cubic feet per second, interpolated between 3000 and 5000 cfs. Then project vertically downward, reading the Time in Days from Clinch River mile 20.8.

Time of water travel for first contaminant to reach the mouth of the Clinch River = 8.3 days.

This time represents the retardation attainable if filling operation is performed for the maximum effect at the mouth. Note that the filling of 8 feet would have to be done in the 7.3 days determined above from Plate 18 for mile 4.4 or at a rate of 1.1 feet per day.

B. Reduction in Peak Concentration Due to Dispersion and Dilution

The Clinch River discharge at mile 20.8 of 1,280 cubic feet per second is used as an ordinate in Plates 12, 13, and 14 of Report No. 1 to determine the reduction due to dispersion. The Duration 1 Day of waste spillage and the average Watts Bar Headwater Elevation 740 (average between the initial elevation 736 and the final elevation 744) are the parameters used in these plates.

The reduction in peak concentration due to dilution is determined from the flows available at each point. The total reduction is equal to the products of the concentration remaining at the point (after dispersion and dilution) subtracted from unity.

	Reduction (Percent)
At Clinch River mile 13.2	
By dispersion for 1 day duration from Plate 12	20
By dilution = $100\left(1 - \frac{1280}{1390}\right)$	8
Total reduction = $100\left[1 - (1 - 0.20)(1 - 0.08)\right]$	26

	Reduction (Percent)
At Clinch River mile 4.4	
By dispersion from Plate 13	51
By dilution $= 100 \left(1 - \frac{1280}{1860 + 3330}\right)$	75
Total reduction $= 100 \left[1 - (1 - 0.51)(1 - 0.75)\right]$	88
At mouth of Clinch River	
By dispersion from Plate 14	66
By dilution (assuming no local inflow between mile 4.4 and the mouth)	75
Total reduction $= 100 \left[1 - (1 - 0.66)(1 - 0.75)\right]$	92

C. Duration of Contamination Under Controlled Releases

Using $x = 1.5\ (T_{min} + D)$ where $D = 1$ day

At Clinch River mile 13.2

$T_{min} = 3.4$ days when regulating for mile 13.2

$x = 1.5\ (3.4 + 1) = 6.6$ days

At Clinch River mile 4.4

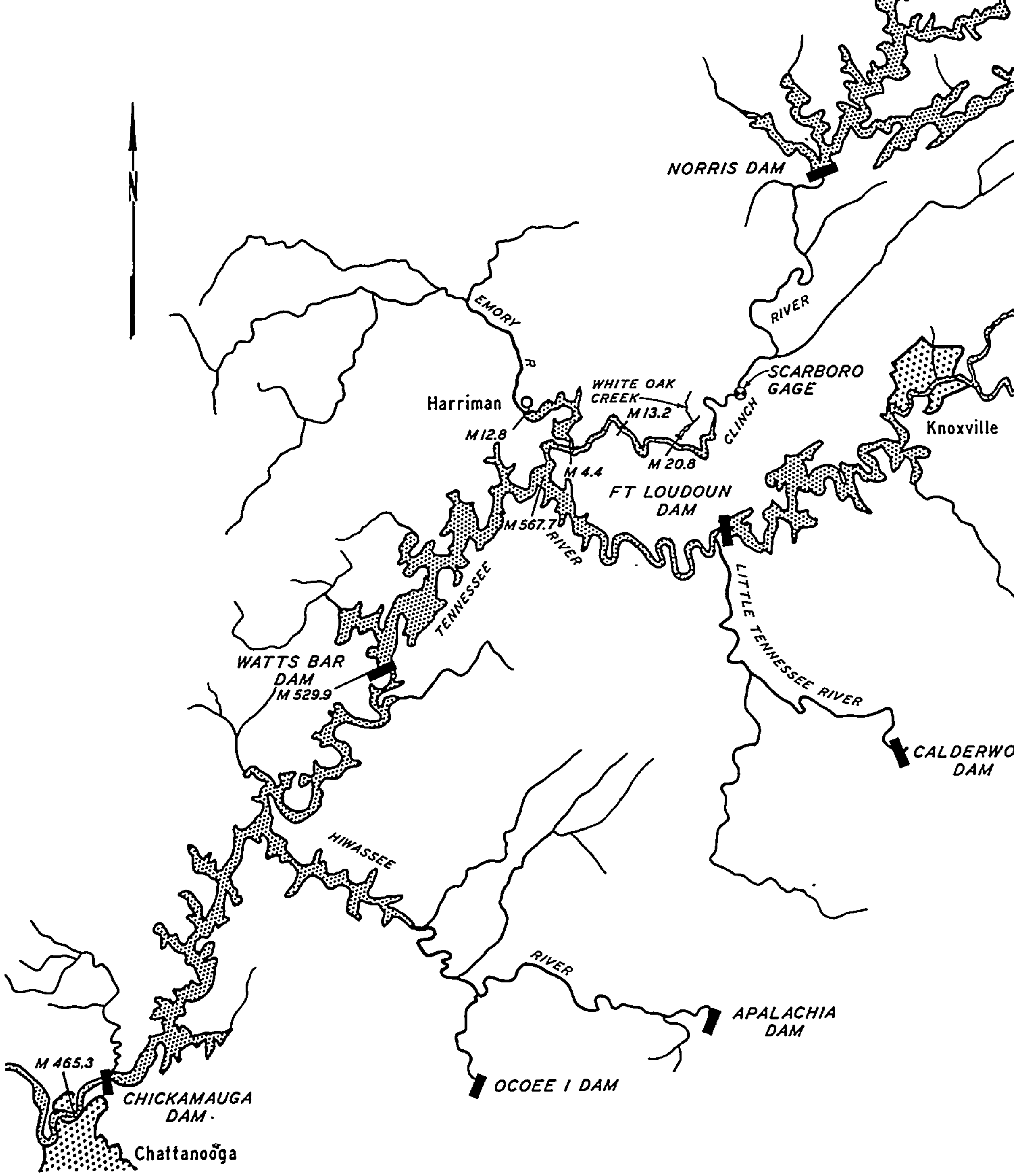
$T_{min} = 7.3$ days when regulating for mile 4.4

$x = 1.5\ (7.3 + 1) = 12.5$ days

At mouth of Clinch River

$T_{min} = 8.3$ days when regulating for mouth

$x = 1.5\ (8.3 + 1) = 14.0$ days



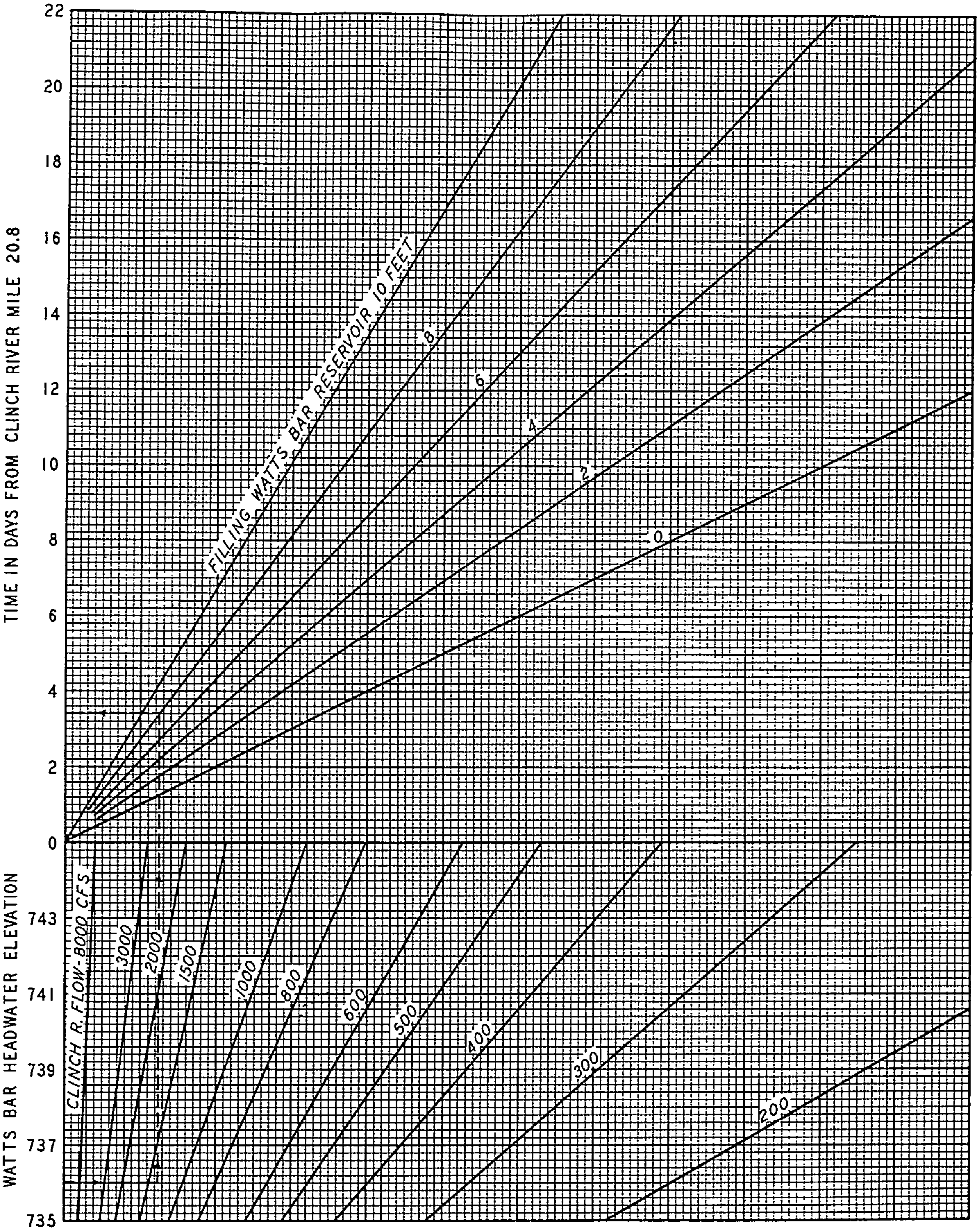
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

AEC SPILLAGE STUDY

LOCATION MAP

OCTOBER 6, 1952

ASF 1256



Time of water travel shown is for first contaminant to reach end of this reach. Period of filling must be equal to the time of travel. Dashed lines with arrows show method of using this multiple correlation, knowing the initial Watts Bar headwater elevation, average Clinch River flow in the reach, and permissible rise in reservoir level.

TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

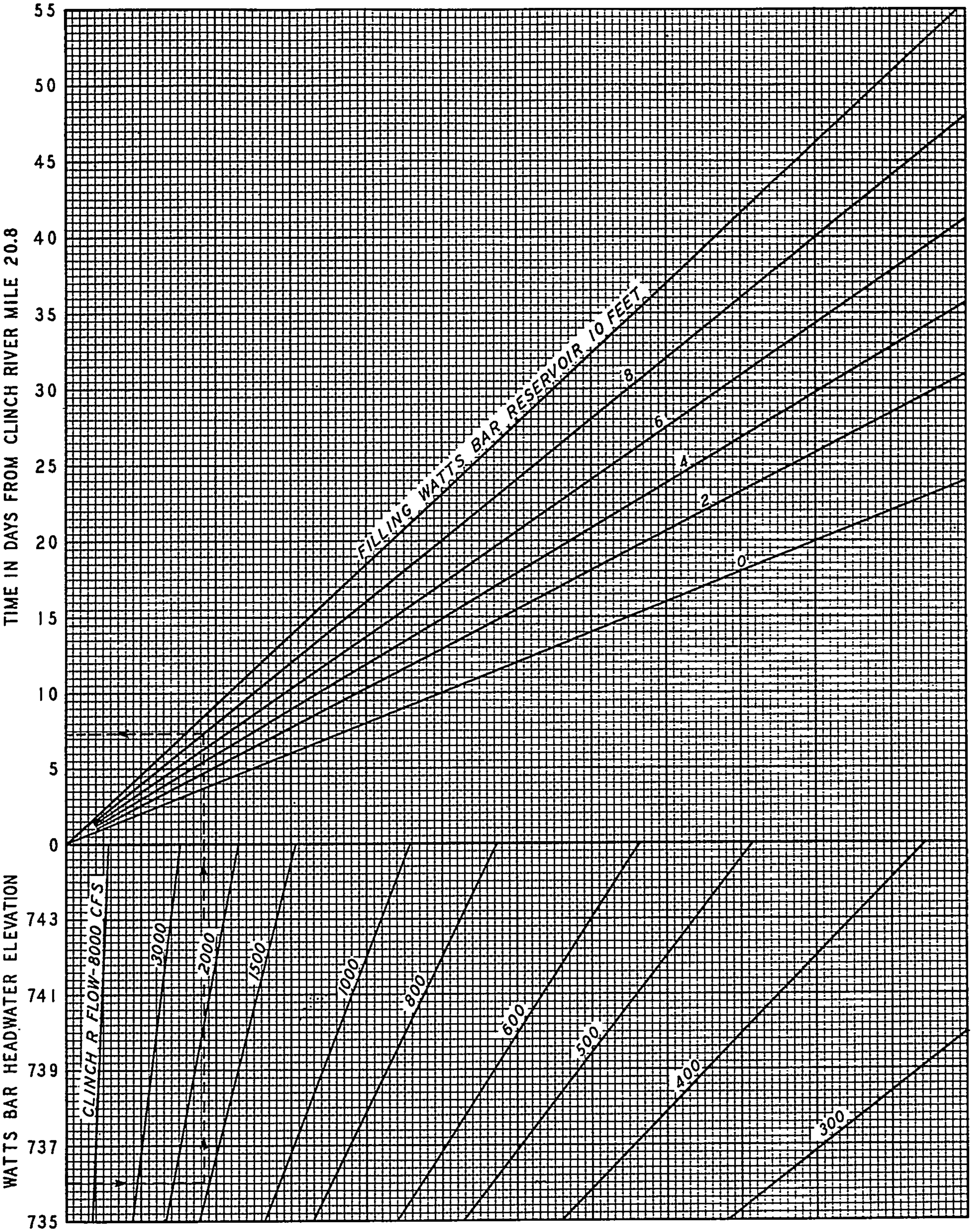
CLINCH RIVER

TIME OF WATER TRAVEL

MILE 20.8 TO 13.2

FILLING WATTS BAR RESERVOIR

FEBRUARY 1, 1953

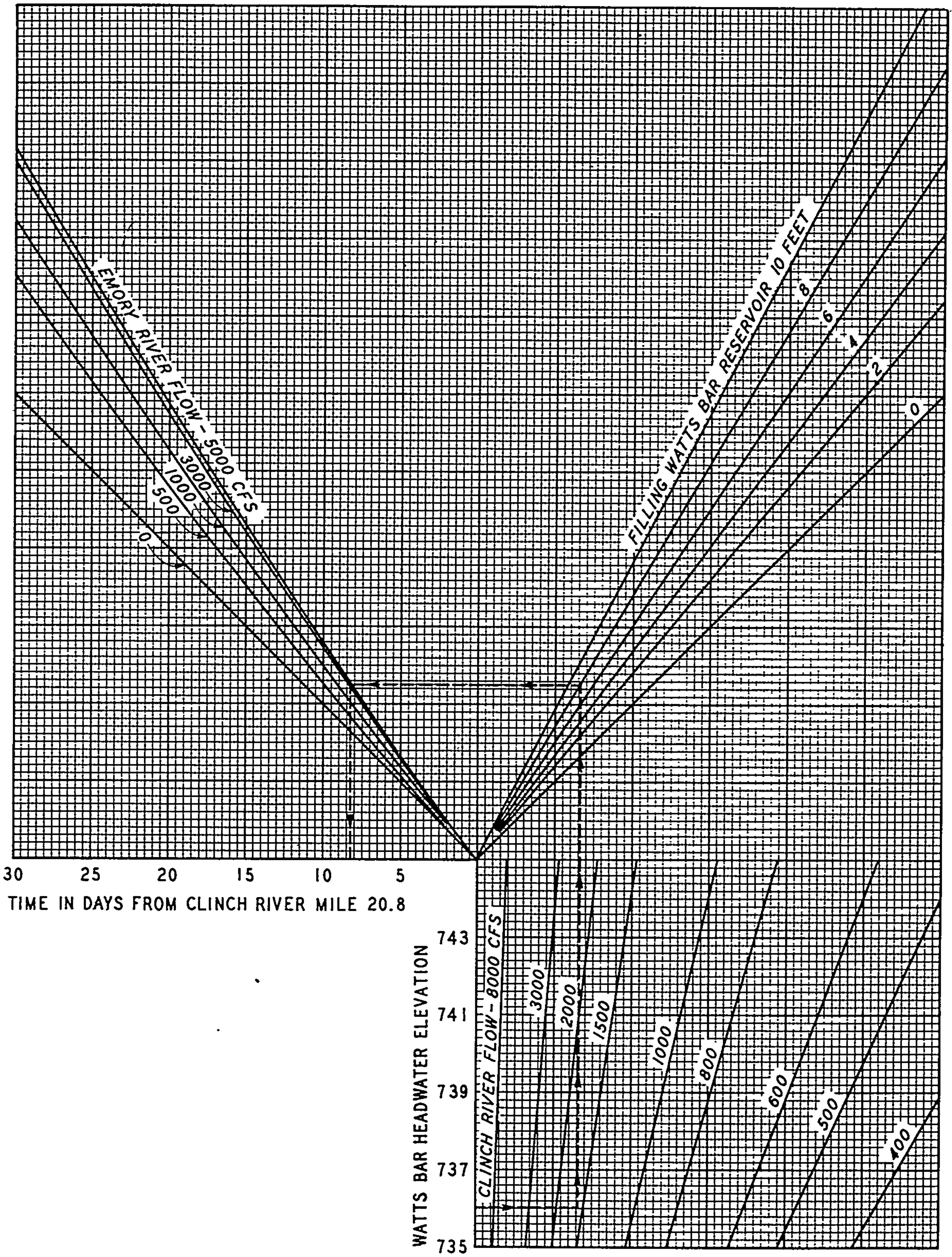


Time of water travel shown is for first contaminant to reach end of this reach. Period of filling must be equal to the time of travel. Dashed lines with arrows show method of using this multiple correlation, knowing the initial Watts Bar headwater elevation, average Clinch River flow in the reach, and permissible rise in reservoir level.

TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

CLINCH RIVER
TIME OF WATER TRAVEL
MILE 20.8 TO 4.4
FILLING WATTS BAR RESERVOIR

FEBRUARY 1,1953



Time of water travel shown is for first contaminant to reach end of this reach. Period of filling must be equal to time of travel from Mile 20.8 to 4.4 determined from Plate 18. Dashed lines with arrows show method of using this multiple correlation, knowing the initial Watts Bar headwater elevation, average Clinch River flow between Miles 20.8 and 4.4, average Emory River flow at the mouth, and permissible rise in reservoir level.

TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

CLINCH RIVER

TIME OF WATER TRAVEL

MILE 20.8 TO MOUTH

FILLING WATTS BAR RESERVOIR

FEBRUARY 1, 1953

Radiation
B

Tennessee Valley Authority
Division of Health and Safety
Environmental Hygiene Branch

EFFECT OF ACCIDENTAL SPILLAGE OF RADIOACTIVE WASTES INTO CLINCH RIVER

Report No. 3

METHOD OF STUDY

Chattanooga, Tennessee
October 1957

Tennessee Valley Authority
Division of Health and Safety
Environmental Hygiene Branch

EFFECT OF ACCIDENTAL SPILLAGE OF RADIOACTIVE WASTES

INTO

CLINCH RIVER

Report No. 3

METHOD OF STUDY

Abbreviations and Locations

Locations on Plate 1 are designated by abbreviations including letters designating river (Cl.-Clinch, Em.-Emory, and Te.-Tennessee) and numbers designating river mileage, i.e., miles above the mouth of the river. The specific locations used in this study are:

Cl. 20.8 - Clinch River at the mouth of White Oak Creek where wastes from Oak Ridge National Laboratory enter Clinch River.

Cl. 13.2 - Clinch River at K-25 steam plant intake. The original request for information presumed the water plant intake to be at Cl. 13.2 but it is actually at Cl. 14.4. The accuracies developed in these studies permit the use of the same flows and times of travel for both locations.

Cl. 4.4 - Clinch River at the mouth of Emory River, in effect the water intake for Kingston Steam Plant.

Cl. 0.0 and Te. 567.7 - Clinch and Tennessee Rivers at the confluence.

Te. 529.9 - Tennessee River at Watts Bar Dam.

Te. 465.3 - Tennessee River at intake for City Water Company, Chattanooga.

Em. 12.8 - Emory River at Harriman water intake.

Summary

A hypothetical study has been made to determine conditions which are calculated to develop downstream from Oak Ridge National Laboratory in the event of the accidental spillage of radioactive substances in the amount of one million (10^6) curies. It has been necessary to make certain assumptions which might not exist in the event of an actual accident, but they were made for illustrative purposes only. If the occasion arises when it is necessary to apply these methods to an actual incident, the lake elevations, streamflows, etc., existing at the time should be used in the calculations. It is not presumed that complete dependence will be placed on mathematical calculations without some measure of monitoring the contamination.

Conclusions in regard to acceptability of the quality of water at various locations under various conditions have been based on values stated in Table 8 as "Emergency Maximum Permissible Concentrations Used in this Study." If future regulations or biological studies indicate values which should be used in preference to these, the conclusions of this study will have to be modified accordingly.

Efforts have been made to anticipate difficulties which might be encountered in performing such a study and point out alternate methods of calculation. An example of this is on pages 12 and 17. There it is explained that minimum flow conditions would not be expected to persist for the long periods of time which would be indicated by strict adherence to the charts and tables. The alternate is to abandon calculations for

minimum flows (unless actually calculating a retardation) and proceed to use mean flows. Even in the use of mean flows from the values tabulated in Report No. 1 with 20-day spill the duration, in many cases, is likely to extend over into the next month when higher flows might be expected. Since there is such a great uncertainty concerning future flows, correction has not been made in the sample calculations for these variations.

The calculations have been made for atomic blast materials assumed to decay with a factor equal to $t^{-1.2}$ and for materials released from a reactor for which no decay was calculated. For materials of other characteristics, the appropriate decay rate would have to be applied. Examples of calculation for minimum, mean, and maximum streamflow rates during stratified and unstratified conditions of Watts Bar Reservoir are given. While data are available in the two reports prepared by the Hydraulic Data Branch for extending the calculations to Chattanooga (Te. 465.3), the sample calculations have not been carried that far in all instances. They were carried at least as far downstream as was necessary to arrive at calculated concentrations which would meet the stated MPC values. The calculations cover both normal operation and managed streamflow conditions.

Some general statements can be made concerning the over-all results of this study, all based on a spill of 10^6 curies entering at Cl. 20.8 and the conditions assumed:

1. A spill of materials which would not undergo decay during the period of study could not be tolerated anywhere in the Clinch River embayment under normal operating conditions.

This statement also applies to Emory River during periods when stratification results in Clinch water underflowing the Emory embayment. Only by diluting the contaminants with the large volume of water in the Tennessee River could concentrations be brought with MPC. The exception to this statement would be release over a 20-day period into maximum streamflow (see November 20-day spill). Under certain high flow conditions in the summertime, it would be possible for excessive concentrations in the density underflow to reach Watts Bar Dam (Te. 529.9).

Neither dilution (25,000 cfs) nor retardation would result in acceptable conditions at Kingston Steam Plant (Cl. 4.4). About the only benefit which could be realized at K-25 and Kingston Steam Plant (Cl. 13.2 or Cl. 4.4) from water management would be: (a) delay (by retardation) to permit provision of a substitute supply, or (b) rapid flush of the contamination past the points (by dilution) so as to reduce the time of shutdown which might otherwise be required.

2. For atomic blast material, normal operating conditions or dilution operation would not result in acceptable concentrations at K-25 (Cl. 13.2). Retardation could produce acceptable concentrations at Cl. 13.2 provided it could be placed in effect during the period May to November

and the contamination did not get into cold Norris water during stratified season.

3. Concentrations from atomic blast reaching Kingston Steam Plant (Cl. 4.4) and points farther downstream would be within MPC values during either normal operating or regulated flow conditions. For spills of larger proportions, retardation might be required to provide additional protection at Cl. 4.4 where further improvement might be by as much as a factor of 20, depending on specific conditions.

4. During stratified reservoir conditions it might be possible to provide substitute sources of water for K-25 from Poplar Creek and for Kingston Steam Plant by a temporary intake from the warm surface layer of the Clinch River, provided the contamination had not been dispersed into them. The success of this operation for Kingston Steam Plant would depend on the development or maintenance of a cold water density underflow carrying contamination in the lower strata of the Clinch River. In general, this would require Clinch River flows between 1000 and 7000 cfs in the reach above the mouth of the Emory River. The suitability of Poplar Creek for use at K-25 would have to be determined in view of the possibility of blast material reaching Poplar Creek as well as White Oak Creek.

Basic Data

In the event of an accidental spillage which is expected to have adverse effects downstream, it is necessary to assemble certain basic information before any calculation of these effects can be undertaken. A list of these items and where to obtain the information is given in the following questions and answers:

1. Q. Location of spill.

   A. ORNL Division of Operations or Health Physics.
   Call shift supervisor, telephone ORNL 6606
   (from Chattanooga to Oak Ridge, LD-220).

2. Q. Quantity of spill, age, and decay rate

   A. Same as above.

3. Q. Period of holdup or time it is expected to reach Clinch River.

   A. Health Physics, Area Monitoring Group, operates White Oak Dam, H. H. Abee.

   (1) Arrange to close gates at dam and impound creek flow.

   (2) Determine inflow at gage above White Oak Lake by observing gage height and applying it to rating table supplied by USGS. Table 7. (This table is corrected to 1-4-57 and more recent one may be available from the U. S. Geological Survey, Surface Waters Division Office, Knoxville, telephone 2-7918.)

(3) Determine holdup time possible by calculation using inflow determined in (2) and the elevation-volume curve (dashed line) on Plate 20. This is the same curve as that used by the Hydraulic Data Branch in the White Oak Lake Sediment Investigations. This chart was distributed as an addendum to Report ORNL 562 "Studies of White Oak Creek Drainage System. I - Drainage Area of the Creek and Capacity of White Oak Lake."

4. Q. Duration and concentration of spill from White Oak Creek.

   A. To be calculated by Area Monitoring Group. (Using flow at Cl. 20.8 from item 7 below.)

5. Q. Condition of stratification of Watts Bar Lake.

   A. (a) October - April generally not stratified.

   (b) May - September Watts Bar Reservoir stratified, Clinch River embayment stratified, provided Norris release is more than 1000 cfs and not more than 7000 cfs. (Below Emory River 10,000 cfs required to break up stratification.)

6. Q. Elevation of Watts Bar Lake.

   A. Call TVA River Forecaster, telephone 2-7181, ext. 681, Knoxville, Tennessee. If unable to reach that office, determine from Daily River Bulletin issued by USTVA-USWB.

Received by R. J. Morton and H. H. Abee. Three-day predictions on reverse side are usually sufficiently accurate.

7. Q. Flow in Clinch River at:

(1) Cl. 20.8

(A1) Determine flow at Scarboro gage on Clinch River by: Telephone H. H. Abee at 6948. Use 24-hour average noon to noon. Determine discharge from Norris (previous 24 hours from midnight to midnight) from Daily River Bulletin and subtract from Scarboro flow to determine local inflow below Norris. Multiply this figure for side drainage by $\frac{435}{388}$ which is the ratio of the drainage area above White Oak Creek (Cl. 20.8) to that above Scarboro gage (Cl. 38.9). To determine flow at Cl. 20.8 algebraically add this amount to the Norris discharge previously subtracted.

(2) Cl. 13.2

(A2) Calculate the same as at 20.8 except drainage area factor is $\frac{475}{388}$.

(3) Cl. 4.4

(A3) Determine the flow in Emory River at Oakdale from Daily River Bulletin and increase it by the ratio of drainage areas $\frac{865}{764}$ to approximate flow at mouth of Emory River. Calculate Clinch River flow at (above) mouth of Emory (Cl. 4.4) by calculating as for Cl. 20.8 except the drainage area factor is $\frac{629}{388}$. Use the total of these two quantities as flow below mouth of Emory.

(4) Cl. 0.0

(A4) Same flow as at Cl. 4.4. Additional drainage area inconsequential.

8. Q. Watts Bar Reservoir inflow.

A. See Question 6. From TVA River Forecaster or from Daily River Bulletin.

9. Q. Flow in Tennessee River at Watts Bar Dam.

A. Same as 8.

10. Q. Chickamauga Lake level and flow in Tennessee River at Chattanooga.

A. Same as 8.

United States
Department of the Interior
Geological Survey
Water Resources Division

TABLE 7

Rating Table For White Oak Creek

Below ORNL Near Oak Ridge, Tennessee

Gage Height feet	Discharge cfs	Difference cfs	Gage Height feet	Discharge cfs	Difference cfs	Gage Height feet	Discharge cfs	Difference cfs
0.00			1.60	21		3.20	63	
					2			5
0.10			1.70	23		3.30	68	
					2			5
0.20			1.80	25		3.40	73	
					2			6
0.30			1.90	27		3.50	79	
					2			6
0.40			2.00	29		3.60	85	
					2			8
0.50			2.10	31		3.70	93	
					2.5			12
0.60	1.6		2.20	33.5		3.80	105	
		1.8			2.5			16
0.70	3.4		2.30	36		3.90	121	
		1.8			2.5			18
0.80	5.2		2.40	38.5		4.00	139	
		1.9			2.5			20
0.90	7.1		2.50	41		4.10	159	
		1.9			2.5			22
1.00	9.0		2.60	43.5		4.20	181	
		2			2.5			24
1.10	11		2.70	46		4.30	205	
		2			3			26
1.20	13		2.80	49		4.40	231	
		2			3			28
1.30	15		2.90	52		4.50	259	
		2			3			30
1.40	17		3.00	55		4.60	289	
		2			4			32
1.50	19		3.10	59		4.70	321	
		2			4			34

United States
Department of the Interior
Geological Survey
Water Resources Division

TABLE 7 (Continued)

Rating Table for White Oak Creek

Below ORNL Near Oak Ridge, Tennessee

Gage Height feet	Discharge cfs	Difference cfs	Gage Height feet	Discharge cfs	Difference cfs	Gage Height feet	Discharge cfs	Difference cfs
4.80	355		5.20	511		5.60		
		36			44			
4.90	391		5.30	555		5.70		
		38			46			
5.00	429		5.40	601		5.80		
		40			48			
5.10	469		5.50	649				
		42						

Tentative 1-4-57

Method of Calculation

A calculation sheet may be set up similar to the attached form, Table 9.

In Appendix C, the detailed instructions are given for making the calculations in Table 9. In order to give specific examples in these instructions the calculations in Appendix C are a part of the calculations necessary for Appendix A and Appendix B. In Appendix A, the calculations are given for a hypothetical spill of 10^6 curies during November when Watts Bar pool would be non-stratified and with a stated pool elevation of 736. The calculations are presented for the various combinations of conditions including duration of spill; 6 hours, 1 day, or 20 days, into Clinch River during minimum flow, mean flow, or maximum flow for November. In Appendix B, the corresponding calculations are given for reservoir stratification conditions during June when the pool level is 740. Such a spill, 10^6 curies, was selected arbitrarily as a value which can easily be scaled up or down. When considering that all the debris and fission products from an atomic blast would not be soluble and all of the soluble material might not find its way to the Clinch River at one time, it is conceivable that a spill of this size could occur. For uniformity and ease of calculation, a hypothetical spill of the same magnitude is used for reactor release without intending to imply that such a quantity of soluble radioactive isotopes would result from an accident involving any of the reactors or storage facilities at ORNL at the present time. In each case, the assumption was made that all the radioactive material remains in solution and that the conditions of streamflow which existed at the time of the spill would continue throughout the period covered by the calculation; that is, until the contaminated water reached and passed the downstream point being investigated. Obviously, these assumptions are fallacious under conditions assumed in several of the calculations. For example, since rainfall and streamflow in the region will rarely continue unchanged for over one week, it would be unreasonable to assume that November minimum flow of 453 cfs at Clinch River mile 20.8 and 10,300 cfs at Tennessee River mile 529.9 would persist for the 85.4 days required in the calculation for the contaminated water to reach and pass Watts Bar Dam. By the end of 85 days (sometime in January or February) the minimum flows would have been augmented by winter runoff, and the time of passage would have been reduced accordingly. The January minimum flows for these same points are 1,620 cfs and 15,800 cfs, respectively, and the mean flows are probably three to five times higher still. However, dependence would not necessarily be placed on calculations for such an extended period. Adequate time would be available for establishment of a sampling or monitoring program.

It is believed that the calculation for stratified conditions is much less dependable than that for non-stratified conditions. In fact, the variables are so capricious during stratification that assistance should be requested from the hydraulic engineers (Hydraulic Data Branch, Division of Water Control Planning) should the spill occur during this season (May - September).

Maximum Permissible Concentrations

Authorities on radiological protection agree that "all unnecessary exposure to radioisotopes should be avoided. However, it is often impracticable, if not impossible, to prevent some radioisotopes from entering the body. Therefore, it is desirable to establish levels of maximum permissible exposure to serve as guides to safe operation and upper levels of exposure."*

The maximum permissible concentration most commonly specified is 10^{-7} microcuries per milliliter for unknown mixtures of beta and gamma emitting radioisotopes in water beyond the areas that are under control of the installation responsible for the contamination. Handbook 52 of the National Bureau of Standards* also lists recommended values of maximum permissible concentrations of certain specific isotopes in drinking water, calculated so that no part of the body will encounter an exposure of more than 0.3 rem per week.

In the event of a disaster or emergency such as a reactor accident, a nuclear explosion, accidental spillage, etc., somewhat higher concentrations could be tolerated for short periods without excessive hazard. The Federal Civil Defense Administration published the following emergency acceptable concentrations in Technical Bulletin TB-11-9, December 1952:

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*"Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water," National Bureau of Standards Handbook 52, March 20, 1953.

Estimated Consumption Period	Beta-Gamma Concentration
10 days immediately after atomic attack	9×10^{-2} µc/cc
30 days immediately after atomic attack	3×10^{-2} µc/cc

These are the same limits as set by "AEC Contract Policy and Operations," January 1951, for personnel who may be called upon in emergency to cope with radiological disasters in war or peace. They are plotted as curves 7 and 8 on Plate 21. For longer periods of consumption or for older fission products, some emergency level was desired.

In "Recommendations for Civil Defense Relative to Radiological Safety," (UCLA-113), Dr. W. F. Bale suggested MPC values calculated on a total "hazard" exposure of 50 roentgens for periods of use of from 10 days to a year during the first 50 days after a blast or during the interval from 50 days to 2 years after the blast. These periods of consumption and intervals after blast would be useful in considering accidental spillage (or enemy action) but the total exposure is rather high to apply to general population, even if only for study of hypothetical cases.

K. Z. Morgan and C. P. Straub* specified 10^{-2} µc/cc as MPC for use in extreme emergency and only during the first week following atomic explosion. This appears as curve 3 on Plate 21. They also derived a formula, $MPC = Kt^{-1.2}$ where $K = 10^{-3}$ for water. Using this

*"External and Internal Exposure to Ionizing Radiation and Maximum Permissible Concentration (MPC) of Radioactive Contamination in Air and Water Following an Atomic Explosion," AECU-2332, Supt. of Documents, (Physical Review 87:178, 1952).

formula, curve 4 on Plate 21 is several orders of magnitude lower than all other curves shown.

C. P. Straub* has calculated MPC values for water which, if consumed at the period and for specified number of days after an atomic blast, would administer a dose of 25 rads. These are plotted as curves 1 and 2 for 1 day and 30 days' intake, respectively, on Plate 21.

In private conversations (February 21, 1957), K. Z. Morgan suggested that for concentrated exposure in emergency the exposure limit recommended for ORNL employees might be applied to downstream civilian populations. This limit would be ten times the normal occupational exposure limit (0.3 rem/wk.) and in one week would total 3.0 rem (provided there were no further exposures for the next twelve weeks). On this basis, F. L. Parker has calculated water MPC values following an atomic blast which are shown for 7-day and 30-day intake in curves 5 and 6, respectively, Plate 21. These calculations do not take into account the isotopes of less than one percent predominance as do Straub's values and therefore may be less valid. Parker has made the corresponding calculations to cover spillage of fission products resulting from a reactor release after one year's operation, specific power of 20 mw/ton (2% enrichment). These MPC's for one week and for 30-day intake are given in curves 9 and 10, Plate 21.

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*"Emergency Maximum Permissible Concentration Values for Water," C. P. Straub, Paper 193, Nuclear Engineering and Science Congress, Cleveland, Ohio, December 12-16, 1955.

There is considerable variation between these values, so, for the purpose of this report the values appearing in the following table have been selected as MPC values which will meet all the above emergency recommendations except the Morgan-Straub formula, MPC = $Kt^{-1.2}$:

TABLE 8

Emergency

Maximum Permissible Concentration Used in this Study

($\mu c/cc$ Beta-Gamma)

Days After Atomic Blast or Reactor Release	Wastes from Atomic Blast: Less Than 7-day Use	Wastes from Atomic Blast: 8-30-day Use	Wastes From Reactor Release: Less Than 7-day Use	Wastes From Reactor Release: 8-30-day Use
1	$9x10^{-3}$	$3x10^{-3}$	$6x10^{-3}$	$1x10^{-3}$
10	$9x10^{-3}$	$3x10^{-3}$	$9x10^{-3}$	$2x10^{-3}$
30	$9x10^{-3}$	$3x10^{-3}$	$9x10^{-3}$	$2x10^{-3}$
50	$9x10^{-3}$	$3x10^{-3}$	$9x10^{-3}$	$2x10^{-3}$
100	$9x10^{-3}$	$3x10^{-3}$	$9x10^{-3}$	$2x10^{-3}$

Discussion of Normal Operating Conditions

Spill of Reactor Release Material

The MPC values used in the calculations (Appendixes A and B) of downstream conditions resulting from wastes originating from reactor release have been calculated taking into account decay of the isotopes originally present. However, the average concentrations which are calculated for the downstream points under various conditions of flow (and consequently of time) have not been reduced for the effect of decay. The decay function approximates $t^{-0.3}$ in which t is the time since release of the fission products from the reactor. This factor is of small consequence when compared to the influence exerted by decay of radioactive materials after an atomic blast, where the factor is $t^{-1.2}$.

The hydraulic engineers have made the general statement that, on the average, weather and consequently streamflow conditions can be expected to change at about seven-day intervals. It would therefore be unreasonable to presume that minimum streamflow would persist for the three and four weeks, and longer, periods which result from applying these methods of calculation to some of the downstream points under study. Therefore, the calculations involving minimum flows are not extended beyond Cl. 13.2 for the hypothetical proportion of 10^6 curies which would be permissible. Even for this station the calculated time of first arrival during June minimum flow exceeds one week and the duration exceeds two weeks. For June (stratified) flows it would be more reasonable to use mean streamflow.

Under any of the conditions of streamflow, stratification, or duration of release investigated, the concentration of radioactive materials from a reactor release in the amount of 10^6 curies would be excessive at Cl. 13.2.

Generally speaking, excessive concentrations would exist under most of the conditions investigated until the contamination reached the Tennessee River where additional dilution was available. Even there and at Te. 529.9 excessive concentrations would result from a 6 or 24-hour spill into June maximum flow when considering only the stratified underflow and not the entire cross-section. Since this stratification would be broken up by passing through Watts Bar Dam and Chickamauga Reservoir, the concentrations reaching Te. 465.3 under maximum flow conditions would be within MPC.

Spill of Atomic Blast Material

Strictly speaking, one would expect the wastes from an atomic blast to be released immediately. However, rainfall might flush off ground accumulations over a somewhat extended period. It might even be possible to impound a large portion of the surface runoff in White Oak Lake and release it gradually. Therefore, calculations have been made for spills of 6-hour, 24-hour, and 20-day duration.

If released uniformly during 20 days, the concentrations at the downstream locations would be permissible under any of the conditions of stratification or streamflow investigated.

If released during 6 or 24 hours, the concentrations at Cl. 13.2 would be excessive for June but not for November minimum flows. Either

June or November mean flow would carry the contamination released during 6 or 24 hours down to Cl. 13.2 so quickly that the concentrations would be excessive. This statement would also apply, for the most part, for maximum flow, although under certain conditions the dilution might be adequate to result in acceptable concentrations.

At the points investigated farther downstream (Cl. 4.4 and beyond), concentrations resulting from 6 or 24-hour spill of 10^6 curies from an atomic blast would be tolerable even when considering the stratified underflow. (This statement is made as a generalization even though the calculations show only 94 percent would be permissible at Cl. 4.4 when spilled into November mean or maximum flow. It should be pointed out that in the hydraulic calculations the flows and consequently dilutions may be accurate to within plus or minus 10 percent, and actual field measurements of time of water travel indicate the theoretical times of travel may need to be increased 15 percent. Consequently, it is not unreasonable to say that a value appearing as 94 percent in the calculation would be acceptable.)

Comparison of Stratified and Non-Stratified Conditions

In general, streamflow during the winter (non-stratified) season is greater than during the summer season. While the higher flow (higher minimum, mean, and maximum) than the summer flow results in carrying the contamination downstream in a shorter period of time, the greater dilution would result in lower concentration of contaminants.

During the stratified season, the minimum flow in the Clinch River is too little to result in upstream flow in the Emory River. The maximum flow, as tabulated by months, is enough to occupy the entire cross-section of the Clinch River and in the Emory River is enough to prevent the upstream flow of Clinch River water. Mean flow in the Clinch River during stratified conditions is very close to the lowest flow which, if maintained for a week, could produce a flow of Clinch water upstream on the bottom of the Emory River. If such a flow did result in contamination reaching the Harriman intake, Em. 12.8, the concentration would be about three times MPC for reactor release material for the calculated duration (June mean flow). If the contamination was from an atomic blast, the elapsed time would be sufficient for decay to bring the concentration well within the MPC.

Dilution

The only source of dilution water for this reach is Norris Dam and the channel storage in the river between Norris and Cl. 13.2. It would not be necessary for the actual water released at Norris to arrive at this location in order to provide dilution. Sustained release from Norris will create a wave, or rather a surge, in the river channel and the water stored in the channel will, in effect, be pushed ahead and become available for dilution purposes sometime before the actual water released at Norris reaches the downstream point. Within the range of releases which could be made at Norris without excessive flood damage, the minimum time of wave travel is 14 hours (see Plate 24). Actual water travel would require over 50 percent longer time but, if the Norris release is sustained, the surge would persist until time for the water arrival. If the spill occurred at a time when the time of travel from Cl. 20.8 to 13.2 is less than 14 hours and it could not be delayed in White Oak Lake, it would be impossible to provide any further protection at that point by dilution. Referring to Plate 2, Report No. 1, it can be seen that for Watts Bar pool elevation 736 (low, winter) this critical flow is about 4500 cfs and for pool elevation 740 (normal, summertime) on Plate 5 about 6000 cfs.

A flow of 25,000 cfs is considered to be bank-full stage on the Clinch River and, while certain farm lands may be flooded at lower flows, this quantity was used in these dilution calculations. If it were possible to so regulate flows as to provide 25,000 cfs flow to receive a 6-hour spill at Cl. 20.8, the concentration at Cl. 13.2 would exceed MPC for reactor release by a factor of 6 or for atomic blast by a factor of 4. In other words, considerable improvement over normal operating conditions could be accomplished by diluting the reactor released material, but, because of reduced time of travel, the dilution to this extent of atomic blast material would result in less tolerable concentrations at Cl. 13.2. At Cl. 4.4 the improvement by dilution of reactor release material over mean flow (either June or November) would be by a factor of almost 2 but, because of reduced time of travel and duration, would not be substantial improvement over conditions of a spill into maximum Clinch River flow. Likewise, high dilution flows would sweep the contamination from an atomic blast down to Cl. 4.4 in such a short time that concentrations would actually be higher (less acceptable) than under normal operating conditions. For points in the Tennessee River and farther downstream, the November situation in general would be that the dilution operation would result in concentrations somewhat less tolerable than would result from normal operating flow, either mean or maximum. When considering the entire cross-section of the river and Watts Bar Reservoir, this same statement would apply to summertime concentrations as well as non-stratified flow. However, the high flow for dilution would not permit stratification to develop and the downstream concentrations resulting from dilution being spread throughout the cross-section would be somewhat more acceptable than the concentrations which would otherwise exist in the more dense thermal stratification underflow. When considering atomic blast material for which radioactive decay is a significant factor, the high flow for dilution would under all circumstances produce worse conditions downstream than would the normal operating flows investigated.

Should the spill from reactor release at Cl. 20.8 last for 24 hours during November, 25,000 cfs dilution would be able to improve by a factor of 2 to 4 the concentrations at the downstream points in the Clinch River but would not accomplish much reduction in concentration in the Tennessee. Because of shorter duration at Watts Bar Dam under dilution than under mean flow conditions, and consequent lower MPC, the contamination might be somewhat more tolerable. (This would, however, be largely dependent on the relative values accepted for MPC.) As in the spill of shorter duration, normal operating flow would be somewhat more favorable than dilution when considering atomic blast materials for which decay is important. During June stratification, the situation would be comparable except dilution might accomplish slightly greater improvement when considering the stratified underflow.

It must be realized that release of stored water from Norris in these quantities for the purpose of dilution is dependent upon the availability of the water. Over prolonged periods this size release could exhaust the storage and produce serious effects upon the ability of the system to meet power requirements. For example, if Norris were near the low water level that may be experienced in November, there would not be enough water in storage, even if it could all be withdrawn, to provide a continuous flow of 25,000 cfs for seven days. For this reason the calculation has not been made for potential relief by dilution during the 20-day hypothetical spill.

Retardation

Another possibility for the management of wastes after release into the Clinch River would be to retard the passage of the wastes out of the Clinch River embayment by special reservoir operations. This would involve the raising of Watts Bar Lake level and the concurrent reduction of inflow through the Clinch River by discontinuing releases at Norris Dam. Retardation could be accomplished in this manner provided the contamination spilled at Cl. 20.8 did not get into a stratum of cold Norris water during stratification season. In this latter case, there would be no way of preventing the cold, naturally dense, water from flowing down along the bottom of the Clinch River to the Tennessee River and on to Watts Bar Dam. The discussion that follows will be on the assumption that the spill is retained in White Oak Creek (or elsewhere) until the last of the cold water from Norris has passed the point of release.

During both the months investigated (June and November) it would theoretically be possible to retard the passage of contamination so that the concentration at Cl. 13.2 would be within the MPC for atomic blast wastes. This is, of course, assuming local inflow not exceeding the mean daily local inflow as listed in Table 5 (Report No. 2). While flows less than these amounts might be encountered during any month of the year, greater flows might also be encountered. From the results of the calculations and reference to Table 5, it would appear that there would be very little chance of accomplishing retardation to provide acceptable concentrations at Cl. 13.2 unless the retardation could be completed during the period May 1 - November 30 while the mean daily local inflow is less than about 500 cfs.

If the spill consisted of wastes which would not be reduced by radioactive decay, the benefit from a retardation operation would be correspondingly less. The time of arrival at Cl. 13.2 would be delayed by a factor of 2 to 3. The duration of contamination at this point would be increased by a factor of 2 to 3 and the concentration would be reduced proportionately, though not enough to make more than 4 percent of 10^6 curies permissible. The time gained by delaying the arrival of contamination would be beneficial toward obtaining a substitute water supply or making emergency arrangements.

Once the retardation operation had been completed for the expressed purpose of providing maximum protection at Cl. 13.2, no further delay could be accomplished. Contaminated water would have already begun to arrive at Cl. 4.4 and it would be necessary to begin releasing water at Watts Bar Dam which would result in an acceleration of the flow in the Clinch River. However, the concentrations (of either reactor release or atomic blast materials) would be less at Cl. 4.4 and downstream points than the concentrations at Cl. 13.2, the point for which maximum protection was sought. No definite statement can be made concerning duration at the downstream points since it would depend on the quantity of water released at Watts Bar and at Norris and on the rate of fall of the lake level.

If retardation were undertaken for the maximum benefit at Cl. 4.4, the time of first arrival would be increased in June from 2 days (for mean flow) to 38 days (for mean local inflow only). The duration of contamination would be increased in about the same proportion and the average concentration would be cut only by 50 percent for reactor release but by 98 percent for blast material. In November, the time gain by retardation would be almost 37 days, the concentration would be reduced by a factor of 10 for reactor material, the duration would be increased by a factor of almost 15, and the concentration for blast material would be reduced 83 percent.

While operating for maximum benefit at Cl. 4.4 the retardation would require about 13 days for contamination to reach Cl. 13.2 in June or 4 days in November compared with 2 and 1 days for the mean normal operating flows, respectively.

Emory River Mile 12.8

Since the Harriman water intake at Emory River Mile 12.8 will be exposed to contaminated flows in the Clinch River only under certain conditions, it is well to review the effect, if any, on this supply of flow regulation to protect other selected points.

Dilution

Clinch River water does not flow up the Emory River during non-stratified conditions. Clinch River flows in excess of 7000 cfs destroy stratification above the mouth of the Emory River. With releases from Norris to provide dilution during the stratification season the entire cross-section of the Clinch River occupied by the 25,000 cfs would be colder than the small flow in the Emory, and even though stratification was destroyed Clinch River water would flow up the Emory when the flow in it was less than 500 cfs. Sufficient data are not available to predict the time of flow to Em. 12.8 under these conditions.

Retardation

Non-Stratified--Without stratification Clinch River water does not flow up the Emory River.

Stratified--If Norris releases are cut off or the Clinch River flow is held below 3000 cfs for the purpose of retardation, the contamination will not reach Em. 12.8 even during stratification season.

Recommendations

With the continuation and expansion of reactor experiments at Oak Ridge and the continuing accumulation of waste materials in storage (in tanks, pits, or ground storage), it is not unreasonable to conclude that an accident can happen which would jeopardize the water supplies downstream from the installation. In the event of such an accident or enemy action or sabotage, the machinery was established several years ago for "off-site" emergency monitoring. Such monitoring would trace the dispersion and concentration of radioactive contamination as it spread but could not predict concentrations downstream.

Techniques have been set up in the present study for predicting downstream concentrations. Possibilities of water management to alleviate hazardous downstream conditions have been outlined and discussed. These manipulations of reservoir levels and releases cannot be put into operation in a short period of time unless prior agreements have been made and the channels established for analyzing the needs and initiating the regulation.

It is therefore suggested that an interagency group which would be empowered to act quickly should be established. This group should be small, possibly not more than one representative (with alternates) each from Oak Ridge National Laboratory, Atomic Energy Commission, Tennessee Valley Authority, and Tennessee Department of Public Health (or United States Public Health Service or Tennessee River Basin Water

Pollution Control Commission). The representatives should, however, be authorized to call on any of the employees or units of their agencies for assistance and to reach decisions and make commitments for their respective agencies. The creation of such a group would complete the organization for action in event of disaster. It would have the authority for implementing procedures which might be necessary for protecting the population from the hazards of radioactive contaminants in water supply.

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6-Hour Spill of 10^6 Curies

Watts Bar Pool Elevation 736
(Non-Stratified)

November Minimum Flow

1. River	Cl.				Te.	
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9
3. Streamflow, cfs	453	453	554	556	10,300	10,300
4. Initial concentration (10^{-2}uc/cc)	360.87					
5. Time of travel (Tav.), days		5.3	17	28	28	51
6. First arrival (Tmin.), days		3.5	11.3	18.7	18.7	34
7. Duration downstream, (X), days		5.7	17.4	28.4	28.4	51.4
8. Reduction peak by dilution, %		0				
9. Reduction peak by dispersion, %		76				
10. Reduction peak, total (excl.decay)%		76				
11. Corresponding peak, %		24				
12. Corresponding peak (10^{-2}uc/cc)		86.6				
13. Ave.conc.(excl.decay),(10^{-2}uc/cc)		15.8				
14. $t = 1 + \text{Tmin.} \times \frac{X}{2}$ days		7.3				
15. Decay factor to mid-duration ($t^{-1.2}$)		0.09				
16. Ave.conc.(incl.decay),(10^{-2}uc/cc)		1.42				
Normal Operating Conditions						
17. MPC reactor release, uc/cc		$6x10^{-3}$				
18. % of 10^6 curies permissible		3.8				
19. MPC atomic blast, uc/cc		$9x10^{-3}$				
20. % of 10^6 curies permissible		63				
Dilution - Reactor Release						
21. Dilution available, cfs	25,000	25,000	25,000	25,000	35,300	35,300
22. Time of arrival, days		.11	.37	.64	.64	7.2
23. Duration, days		.5	.75	1.02	1.02	7.6
24. Ave.conc.(excl.decay), 10^{-2}uc/cc		3.25	2.16	1.59	1.15	0.15
25. % of 10^6 curies permissible		18.5	27.7	37.7	52.2	400
Dilution - Atomic Blast						
26. Decay factor (atomic blast)		0.72	0.56	0.45	0.45	0.07
27. Ave. conc.(incl.decay), 10^{-2}uc/cc		2.34	1.21	0.72	0.52	0.010
28. % of 10^6 curies permissible		38.5	74.3	12.5	173	9000
Retardation						
29. Mean daily local inflow, cfs	480	530	700	700	10,300	10,300
30. Lake rise during retardation, ft.	9	9	9	9	9	9
31. First arrival, Tmin., days		9.6	21	24	24	47
32. Duration, 1.5 (Tmin. + D), days		14.8	31.9	36	36	71
33. Ave. conc.(excl.decay), 10^{-2} uc/cc		5.22	1.83	1.62	0.11	0.056
34. % of 10^6 reactor curies allowable		3.8	10.9	12.3	182	
35. $t = 1 + \text{Tmin.} \times \frac{X}{2}$		18	38	43	43	
36. Decay factor $t^{-1.2}$		0.03	0.013	0.011	0.011	
37. Ave.conc.(incl.decay), 10^{-2}uc/cc		0.16	0.024	0.018	0.0001	
38. % of 10^6 blast curies permissible		187	1250			

November Mean Flow

1. River	Cl.				Te.		
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9	465.3
3. Streamflow, cfs	4430	4430	5640	5830	25,400	25,400	34,000
4. Initial concentration (10^{-2}uc/cc)	36.9						
5. Time of travel (Tav.), days		0.6	1.8	3.0	3.0	12.3	17.2
6. First arrival (Tmin.), days		0.4	1.2	2.0	2.0	8.2	11.5
7. Duration downstream, (X), days		1.0	2.2	3.4	3.4	12.7	17.6
8. Reduction peak by dilution, %		0	4.5	24.0	82.5	82.5	87.0
9. Reduction peak by dispersion, %		15	48	65	65	97	98
10. Reduction peak, total (excl.decay)%		15	50	73.4	93.9	99.5	99.74
11. Corresponding peak, %		85	50	26.6	6.1	0.5	0.26
12. Corresponding peak (10^{-2}uc/cc)		31.4	18.45	9.8	2.2	0.19	0.10
13. Ave.conc.(excl.decay),(10^{-2}uc/cc)		9.2	4.0	2.1	0.48	0.13	0.0683
14. $t = 1 + \text{Tmin.} \times \frac{X}{2}$ days		1.9	3.3	4.7	4.7	15.5	21.3
15. Decay factor to mid-duration ($t^{-1.2}$)		0.45	0.24	0.16	0.16	0.036	0.025
16. Ave.conc.(incl.decay),(10^{-2}uc/cc)		4.13	0.96	0.34	0.077	0.005	0.0017
Normal Operating Conditions							
17. MPC reactor release, uc/cc		$6x10^{-3}$	$6x10^{-3}$	$6x10^{-3}$	$6x10^{-3}$	$2x10^{-3}$	$2x10^{-3}$
18. % of 10^6 curies permissible		6.5	15.0	28.6	125	154	293
19. MPC atomic blast, uc/cc		$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$
20. % of 10^6 curies permissible		21.8	94	265	1170	18,000	53,000
Dilution - Reactor Release							
21. Dilution available, cfs	25,000	25,000	25,000	25,000	50,400	50,400	
22. Time of arrival, days		.11	.37	.64	.64	5.3	
23. Duration, days		.5	.75	1.02	1.02	5.7	
24. Ave.conc.(excl.decay), 10^{-2}uc/cc		3.27	2.16	1.60	0.90	0.16	
25. % of 10^6 curies permissible		18.3	27.7	37.5	66.7	375	
Dilution - Atomic Blast							
26. Decay factor (atomic blast)					0.45		
27. Ave. conc.(incl.decay), 10^{-2}uc/cc					0.40		
28. % of 10^6 curies permissible					225		

November Maximum Flow

1. River	Cl.				Te.		
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9	465.3
3. Streamflow, cfs	12,700	12,700	19,450	40,500	128,000	128,000	167,000
4. Initial concentration (10^{-2}uc/cc)	12.9						
5. Time of travel (Tav.), days		0.22	0.6	0.73	0.73	2.5	3.7
6. First arrival (Tmin.), days		0.15	0.4	0.5	0.5	1.7	2.4
7. Duration downstream, (X), days		0.6	1.0	1.13	1.13	2.9	4.1
8. Reduction peak by dilution, %		0	34.7	68.8	90.2	90.2	92.4
9. Reduction peak by dispersion, %		0	19	36	36	92	95
10. Reduction peak, total (excl.decay)%		0	47	77	93.7	99.2	99.6
11. Corresponding peak, %		100	53	23	6.3	0.8	0.4
12. Corresponding peak (10^{-2}uc/cc)		12.9	6.8	3.0	0.8	0.1	0.049
13. Ave.conc.(excl.decay),(10^{-2}uc/cc)		5.4	2.1	0.9	0.28	0.109	0.06
14. $t = 1 + \text{Tmin.} \times \frac{X}{2}$ days		1.45	1.9	2.1	2.1	4.15	5.45
15. Decay factor to mid-duration ($t^{-1.2}$)		0.64	0.46	0.41	0.41	0.181	0.131
16. Ave.conc.(incl.decay),(10^{-2}uc/cc)		3.5	0.96	0.37	0.11	0.020	0.008
Normal Operating Conditions							
17. MPC reactor release, uc/cc		$6x10^{-3}$	$6x10^{-3}$	$6x10^{-3}$	$6x10^{-3}$	$6x10^{-3}$	$6x10^{-3}$
18. % of 10^6 curies permissible		11.1	28.6	67	214	550	1000
19. MPC atomic blast, uc/cc		$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$
20. % of 10^6 curies permissible		25.7	94	243	820	4500	11,250

24-Hour Spill of 10^6 Curies

Watts Bar Pool Elevation 736
(Non-Stratified)

November Minimum Flow

1. River	Cl.				Te.	
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9
3. Streamflow, cfs	453	453	554	556	10,300	10,300
4. Initial concentration (10^{-2}uc/cc)	90.22					
5. Time of travel (Tav.), days		5.3	17	28	28	51
6. First arrival (Tmin.), days		3.5	11.3	18.7	18.7	34
7. Duration downstream, (X), days		6.8	18.5	29.5	29.5	52.5
8. Reduction peak by dilution, %		0				
9. Reduction peak by dispersion, %		40				
10. Reduction peak, total (excl.decay) %		40				
11. Corresponding peak, %		60				
12. Corresponding peak (10^{-2} uc/cc)		54.1				
13. Ave.conc.(excl.decay),(10^{-2} uc/cc)		13.3				
14. $t = 1 + Tmin. + \frac{X}{2}$, days		7.9				
15. Decay factor to mid-duration ($t^{-1.2}$)		0.083				
16. Ave.conc.(incl.decay), (10^{-2} uc/cc)		1.10				
Normal Operating Conditions						
17. MPC reactor release, uc/cc		6x10-3				
18. % of 10^6 curies permissible		4.5				
19. MPC atomic blast, uc/cc		9x10-3				
20. % of 10^6 curies permissible		82				
Dilution - Reactor Release						
21. Dilution available, cfs	25,000	25,000	25,000	25,000	35,300	35,300
22. Time of arrival, days		.11	.37	.64	.64	7.2
23. Duration, days		1.61	1.87	2.14	2.14	8.7
24. Ave.conc.(excl.decay), 10^{-2} uc/cc		1.01	0.87	0.77	0.55	0.13
25. % of 10^6 curies permissible		59	69	78	109	154
Dilution - Atomic Blast						
26. Decay factor		0.47	0.39	0.33	0.33	0.06
27. Ave.conc.(incl.decay) 10^{-2} uc/cc		0.48	0.34	0.25	0.18	0.008
28. % of 10^6 curies permissible		188	265	360	500	11,200

November Mean Flow

1. River	Cl.				Te.		
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9	465.3
3. Streamflow, cfs	4430	4430	4640	5830	25,400	25,400	34,000
4. Initial concentration (10^{-2}uc/cc)	9.22						
5. Time of travel (Tav.), days		0.6	1.8	3.0	3.0	12.3	
6. First arrival (Tmin.), days		0.4	1.2	2.0	2.0	8.2	
7. Duration downstream, (X), days		2.1	3.3	4.5	4.5	13.8	
8. Reduction peak by dilution, %		0	4.5	24	82.5	82.5	
9. Reduction peak by dispersion, %		0	10	26	26	89	
10. Reduction peak, total (excl.decay) %		0	14.0	43.8	87.0	98.1	
11. Corresponding peak, %		100	86	56.2	13.0	1.9	
12. Corresponding peak (10^{-2} uc/cc)		9.2	7.9	5.2	1.2	0.17	
13. Ave.conc.(excl.decay),(10^{-2} uc/cc)		4.4	2.7	1.6	0.36	0.12	
14. $t = 1 + Tmin. + \frac{X}{2}$, days		2.4	3.8	5.2	5.2	16.1	
15. Decay factor to mid-duration ($t^{-1.2}$)		0.35	0.20	0.14	0.14	0.04	
16. Ave.conc.(incl.decay), (10^{-2} uc/cc)		1.5	0.54	0.22	0.05	0.005	
Normal Operating Conditions							
17. MPC reactor release, uc/cc		6x10-3	6x10-3	6x10-3	6x10-3	2x10-3	
18. % of 10^6 curies permissible		13.7	22.2	37	167	167	
19. MPC atomic blast, uc/cc		9x10-3	9x10-3	9x10-3	9x10-3	3x10-3	
20. % of 10^6 curies permissible		60	167	410	1800	6,000	
Dilution - Reactor Release							
21. Dilution available, cfs	25,000	25,000	25,000	25,000	50,400	50,400	
22. Time of arrival, days		.11	.37	.64	.64	5.3	
23. Duration, days		1.61	1.87	2.14	2.14	6.8	
24. Ave.conc.(excl.decay), 10^{-2} uc/cc		1.01	0.87	0.77	0.38	0.12	
25. % of 10^6 curies permissible		59	69	78	158	167	
Dilution - Atomic Blast							
26. Decay factor		0.47	0.39	0.33	0.33	0.08	
27. Ave.conc.(incl.decay) 10^{-2} uc/cc		0.48	0.34	0.25	0.13	0.01	
28. % of 10^6 curies permissible		188	265	360	690	3000	

November Maximum Flow

1. River	Cl.				Te.		
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9	465.3
3. Streamflow, cfs	12,700	12,700	19,450	40,500	128,000	128,000	167,000
4. Initial concentration (10^{-2}uc/cc)	3.2						
5. Time of travel (Tav.), days		0.22	0.6	0.73	0.73	2.5	3.7
6. First arrival (Tmin.), days		0.15	0.2	0.5	0.5	1.7	2.4
7. Duration downstream, (X), days		1.72	2.1	2.2	2.2	4.0	5.2
8. Reduction peak by dilution, %		0	34.7	68.8	90.1	90.1	92.4
9. Reduction peak by dispersion, %		0	0	2.0	2.0	72	82
10. Reduction peak, total (excl.decay) %		0	34.7	69.4	90.4	97.2	98.6
11. Corresponding peak, %		100	65.3	30.6	9.6	2.8	1.4
12. Corresponding peak (10^{-2} uc/cc)		3.2	2.1	0.98	0.3	0.09	0.045
13. Ave.conc.(excl.decay),(10^{-2} uc/cc)		1.9	1.0	0.45	0.14	0.078	0.047
14. $t = 1 + Tmin. + \frac{X}{2}$, days		2.0	2.2	2.6	2.6	4.7	6.0
15. Decay factor to mid-duration ($t^{-1.2}$)		0.43	0.37	0.32	0.32	0.16	0.12
16. Ave.conc.(incl.decay), (10^{-2} uc/cc)		0.82	0.37	0.14	0.045	0.012	0.006
Normal Operating Conditions							
17. MPC reactor release, uc/cc		6x10-3	6x10-3	6x10-3	6x10-3	6x10-3	6x10-3
18. % of 10^6 curies permissible		32	60	133	430	770	1280
19. MPC atomic blast, uc/cc		9x10-3	9x10-3	9x10-3	9x10-3	9x10-3	9x10-3
20. % of 10^6 curies permissible		110	243	642	2000	7500	15,000

20-Day Spill of 10^6 Curies

Watts Bar Pool Elevation 736
(Non-Stratified)

November Minimum Flow

1. River	Cl.				Te.	
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9
3. Streamflow, cfs	453	453	554	556	10,300	10,300
4. Initial concentration (10^{-2} uc/cc)	4.51					
5. Time of travel (Tav.), days		5.3	17	28	28	51
6. First arrival (Tmin.), days		3.5	11.3	18.7	18.7	34
7. Duration downstream, (X), days		35.3	47	58	58	81
8. Reduction peak by dilution, %		0				
9. Reduction peak by dispersion, %		0				
10. Reduction peak, total (excl.decay),%		0				
11. Corresponding peak, %		100				
12. Corresponding peak, (10^{-2} uc/cc)		4.51				
13. Ave.conc.(excl.decay),(10^{-2}uc/cc)		2.56				
14. $t = 1 + Tmin. + \frac{X}{2}$, days		22.2				
15. Decay factor to mid-duration ($t^{-1.2}$)		0.024				
16. Ave.conc.(incl.decay), (10^{-2} uc/cc)		0.064				
Normal Operating Conditions						
17. MPC reactor release, uc/cc		2x10-3				
18. % of 10^6 curies permissible		7.8				
19. MPC atomic blast, uc/cc		3x10-3				
20. % of 10^6 curies permissible		470				

November Mean Flow

1. River	Cl.				Te.	
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9
3. Streamflow, cfs	4430	4430	4640	5830	25,400	25,400
4. Initial concentration (10^{-2} uc/cc)	0.46					
5. Time of travel (Tav.), days		0.6	1.8	3.0	3.0	12.3
6. First arrival (Tmin.), days		0.4	1.2	2.0	2.0	8.2
7. Duration downstream, (X), days		30.6	31.8	33.0	33.0	42.3
8. Reduction peak by dilution, %		0	4.5	24	82.5	82.5
9. Reduction peak by dispersion, %		0	0	0	0	19
10. Reduction peak, total (excl.decay),%		0	4.5	24	82.5	85.8
11. Corresponding peak, %		100	95.5	76	17.5	14.2
12. Corresponding peak, (10^{-2} uc/cc)		0.46	0.44	0.35	0.08	0.065
13. Ave.conc.(excl.decay),(10^{-2}uc/cc)		0.30	0.28	0.21	0.05	0.038
14. $t = 1 + Tmin. + \frac{X}{2}$, days		16.7	18.1	19.5	19.5	30.4
15. Decay factor to mid-duration ($t^{-1.2}$)		0.034	0.031	0.028	0.028	0.017
16. Ave.conc.(incl.decay), (10^{-2} uc/cc)		0.010	0.009	0.006	0.0014	0.0007
Normal Operating Conditions						
17. MPC reactor release, uc/cc		1x10-3	1x10-3	1x10-3	1x10-3	1x10-3
18. % of 10^6 curies permissible		33	36	48	200	268
19. MPC atomic blast, uc/cc		3x10-3	3x10-3	3x10-3	3x10-3	3x10-3
20. % of 10^6 curies permissible		3000	3300	5000	21,000	43,000

November Maximum Flow

1. River	Cl.				Te.		
2. Mile	20.8	13.2	4.4	0.0	567.7	529.9	465.3
3. Streamflow, cfs	12,700	12,700	19,450	40,500	128,000	128,000	167,000
4. Initial concentration (10^{-2} uc/cc)	0.16						
5. Time of travel (Tav.), days		0.22	0.6	0.73	0.73	2.5	3.7
6. First arrival (Tmin.), days		0.15	0.2	0.5	0.50	1.7	2.4
7. Duration downstream, (X), days		30.22	30.6	30.73	30.73	32.5	33.7
8. Reduction peak by dilution, %		0	34.7	68.6	90.1	90.1	92.4
9. Reduction peak by dispersion, %		0	0	0	0	0	7
10. Reduction peak, total (excl.decay),%		0	34.7	68.6	90.1	90.1	92.9
11. Corresponding peak, %		100	65.3	31.4	9.9	9.9	7.1
12. Corresponding peak, (10^{-2} uc/cc)		0.16	0.105	0.05	0.016	0.016	0.011
13. Ave.conc.(excl.decay),(10^{-2}uc/cc)		0.106	0.069	0.033	0.01	0.01	0.007
14. $t = 1 + Tmin. + \frac{X}{2}$, days		16.3	16.4	16.9	16.9	18.9	20.3
15. Decay factor to mid-duration ($t^{-1.2}$)		0.034	0.034	0.033	0.033	0.029	0.027
16. Ave.conc.(incl.decay), (10^{-2} uc/cc)		0.004	0.002	0.0011	0.0003	0.0003	0.0002
Normal Operating Conditions							
17. MPC reactor release, uc/cc		1x10-3	1x10-3	1x10-3	1x10-3	1x10-3	1x10-3
18. % of 10^6 curies permissible		94	145	300	1000	1000	1430
19. MPC atomic blast, uc/cc		3x10-3	3x10-3	3x10-3	3x10-3	3x10-3	3x10-3
20. % of 10^6 curies permissible		7,500	15,000	27,000	100,000	100,000	150,000

6-Hour Spill of 10^6 Curies

Watts Bar Pool Elevation 740
(Stratified)

	June Minimum Flow [a]								June Mean Flow								June Maximum Flow					
1. River	Cl.			Em.	Cl.	Te.		Cl.			Em.	Cl.	Te.		Cl.			Em.	Cl.	Te.	
2. Mile	20.8	13.2	4.4	12.8	0.0	567.7	529.9	20.8	13.2	4.4	12.8	0.0	567.7	529.9	20.8	13.2	4.4	12.8	0.0	567.7	529.9
3. Streamflow, cfs	224	224	247	14	262	8200	8200	2820	2820	2890	396	3320	18,900	18,900	7420	7420	7420	5300	9280	32,100	32,100
4. Initial concentration (10^{-2}uc/cc)	730							58							22						
5. Time of travel,(Tav.), days		14	36	None	55	55	80+		1.2	3.0	25.0	3.8	3.8	11.3		0.5	1.5	None	2.2	2.2	8.7
6. First arrival (Tmin.), days		9.3	24		36.6	36.6	54+		0.8	2.0	24.0	2.5	2.5	7.5		0.33	1.0		1.5	1.5	5.8
7. Duration downstream (X), days		14.4	36.4		55.4	55.4	80+		1.6	3.4	25.4	4.2	4.2	11.7		0.9	1.9		2.6	2.6	9.1
8. Reduction peak by dilution, %		0							0	(2.4) 0	(2.4) 0	(15)[b] 0	85	85		0	0		20	(77) 20	(77) 20
9. Reduction peak by dispersion, %		92							38	66	72	76	76	97[c]		21	51		69	69	82
10. Reduction peak, total (excl.decay), %		92							38	66	72	76	96.4	99.55		21	51		75.2	75.2	85.6
11. Corresponding peak, %		8							62	34	28	24		0.45		79	49		24.8		14.4
12. Corresponding peak, (10^{-2}uc/cc)		58.4							36	19.7	16.2	13.9		0.26		17.4	10.8		5.5		3.2
13. Ave.conc.(excl.decay)(10^{-2}uc/cc)		12.7							9.1	(4.2) 4.3	(0.56) 0.57	(2.9) 3.5	0.52	0.19		6.1	2.9		1.7	(0.49) 1.7	(0.14) 0.48
14. $t = 1 + Tmin. + \frac{X}{2}$, days		17.5							2.6	4.7	37.7	5.6	5.6	14.4		1.8	3.0		3.8		11.4
15. Decay factor to mid-duration ($t^{-1.2}$)		0.032							0.32	0.16	0.013	0.13	0.13	0.041		0.49	0.27		0.20		0.055
16. Ave.conc.(incl.decay),(10^{-2}uc/cc)		0.41							2.9	(0.67) 0.69	0.007	(0.38) 0.46	0.068	0.0078		3.0	0.78		0.34	(0.1) 0.34	(0.0077) 0.027
Normal Operating Conditions																					
17. MPC reactor release, uc/cc		2x10^{-3}							6x10^{-3}	6x10^{-3}	2x10^{-3}	6x10^{-3}	6x10^{-3}	2x10^{-3}		6x10^{-3}	6x10^{-3}		6x10^{-3}	6x10^{-3}	2x10^{-3}
18. % of 10^6 curies permissible		1.6							6.6	(14.3) 14.0	(35.7) 35.1	(20.7) 17.1	130	105		9.9	20.7		35.3	(122) 35.3	(143) 42
19. MPC atomic blast, uc/cc		3x10^{-3}							9x10^{-3}	9x10^{-3}	9x10^{-3}	9x10^{-3}	9x10^{-3}	9x10^{-3}		9x10^{-3}	9x10^{-3}		9x10^{-3}	9x10^{-3}	9x10^{-3}
20. % of 10^6 curies permissible		73							31	(134) 130	12,850	(237) 196	1320	11,550		30	115		250	(900) 250	(11,700) 3330

Retardation

29. Mean daily local inflow, cfs	210	230	300	330	300
30. Lake rise during retardation, ft.	5	5	5	5	5
31. First arrival, Tmin., days		21	38	Will	
32. Duration, 1.5 (Tmin. + D), days		32	59	Not	
33. Ave.conc.(excl.decay), 10^{-2}uc/cc		5.55	2.03	Flow	
34. % of 10^6 reactor curies permissible		3.6	9.8	Up	
				Emory	
35. $t = Tmin. + \frac{X}{2} + 1$, days		38	68.5	River	
36. Decay factor[2] $t^{-1.2}$		0.013	0.006		
37. Ave.conc.(incl.decay), 10^{-2}uc/cc		0.05	0.012		
38. % of 10^6 blast curies permissible		600	2500		

a. June minimum flow is not enough to produce stratification.
b. Figures in parentheses apply to the entire cross-section including both underflow and uncontaminated surface layer.
c. Even though the Clinch water does not flow as a distinguishable mass, use Table 2 since it was prepared for this condition.

24-Hour Spill of 10^6 Curies

Watts Bar Pool Elevation 740
(Stratified)

June Minimum Flow[a]

1. River	Cl.			Em.	Cl.	Te.	
2. Mile	20.8	13.2	4.4	12.8	0.0	567.7	529.9
3. Streamflow, cfs	224	224	247	14	262	8200	8200
4. Initial concentration (10^{-2}uc/cc)	182.5						
5. Time of travel (Tav.), days		14	36	None	55	55	
6. First arrival (Tmin.), days		9.3	24		36.6	36.6	
7. Duration downstream (X), days		15.5	37.5		56.5	56.5	
8. Reduction peak by dilution, %		0					
9. Reduction peak by dispersion, %		75					
10. Reduction peak, total (excl.decay), %		75					
11. Corresponding peak, %		25					
12. Corresponding peak (10^{-2}uc/cc)		45.6					
13. Ave. conc.(excl. decay) (10^{-2}uc/cc)		11.8					
14. $t = 1 + Tmin. + \frac{X}{2}$, days		18.1					
15. Decay factor to mid-duration ($t^{-1.2}$)		0.031					
16. Ave. conc. (incl. decay),(10^{-2}uc/cc)		0.37					
Normal Operating Conditions							
17. MPC reactor release, uc/cc		$2x10^{-3}$					
18. % of 10^6 curies permissible		1.7					
19. MPC atomic blast, uc/cc		$3x10^{-3}$					
20. % of 10^6 curies permissible		81					

June Mean Flow

1. River	Cl.			Em.	Cl.	Te.	
2. Mile	20.8	13.2	4.4	12.8	0.0	567.7	529.9
3. Streamflow, cfs	2820	2820	2890	396	3320	18,900	18,900
4. Initial concentration (10^{-2}uc/cc)	14.5						
5. Time of travel (Tav.), days		1.2	3.0	25	3.8	3.8	11.3
6. First arrival (Tmin.), days		0.8	2.0	24	2.5	2.5	7.5
7. Duration downstream (X), days		2.7	4.5 (2.4)	26.5 (15)	5.3 (15)	5.3	12.8
8. Reduction peak by dilution, %		0	0	0	0	85	85
9. Reduction peak by dispersion, %		4	26	34	40	40	90
10. Reduction peak, total (excl.decay), %		4	26	34	40	91	98.5
11. Corresponding peak, %		96	74	66	60	9	1.5
12. Corresponding peak (10^{-2}uc/cc)		13.9	10.7 (3.1)	9.6 (0.46)	8.7 (2.3)	1.3	0.2
13. Ave. conc.(excl. decay) (10^{-2}uc/cc)		5.4	3.2	0.55	2.7	0.41	0.17
14. $t = 1 + Tmin. + \frac{X}{2}$, days		3.2	5.2	38.2	6.2	6.2	14.9
15. Decay factor to mid-duration ($t^{-1.2}$)		0.25	0.14 (0.43)	0.013 (0.006)	0.11 (0.25)	0.11	0.039
16. Ave. conc. (incl. decay),(10^{-2}uc/cc)		1.35	0.45	0.007	0.30	0.045	0.0066
Normal Operating Conditions							
17. MPC reactor release, uc/cc		$6x10^{-3}$	$6x10^{-3}$ (19.4)	$2x10^{-3}$ (43)	$6x10^{-3}$ (26.0)	$6x10^{-3}$	$2x10^{-3}$
18. % of 10^6 curies permissible		11.1	18.8	36	22.2	146	118
19. MPC atomic blast, uc/cc		$9x10^{-3}$	$9x10^{-3}$ (210)	$9x10^{-3}$ (15,400)	$9x10^{-3}$ (360)	$9x10^{-3}$	$9x10^{-3}$
20. % of 10^6 curies permissible		67	200	13,600	300	2000	13,650

June Maximum Flow

1. River	Cl.			Em.	Cl.	Te.	
2. Mile	20.8	13.2	4.4	12.8	0.0	567.7	529.9
3. Streamflow, cfs	7420	7420	7420	5300	9280	32,100	32,100
4. Initial concentration (10^{-2}uc/cc)	5.5						
5. Time of travel (Tav.), days		0.5	1.5	None	2.2	2.2	8.7
6. First arrival (Tmin.), days		0.33	1.0		1.5	1.5	5.8
7. Duration downstream (X), days		2.0	3.0		3.7	3.7 (77)	10.2 (77)
8. Reduction peak by dilution, %		0	0		20	20	20
9. Reduction peak by dispersion, %		0	12		30	30	51
10. Reduction peak, total (excl.decay), %		0	12		44	44	61
11. Corresponding peak, %		100	88		56	56	39
12. Corresponding peak (10^{-2}uc/cc)		5.5	4.8		3.1	3.1 (0.34)	2.1 (0.12)
13. Ave. conc.(excl. decay) (10^{-2}uc/cc)		2.8	1.8		1.2	1.2	0.43
14. $t = 1 + Tmin. + \frac{X}{2}$, days		2.3	3.5		4.4	4.4	11.9
15. Decay factor to mid-duration ($t^{-1.2}$)		0.37	0.22		0.17	0.17 (0.058)	0.052 (0.0062)
16. Ave. conc. (incl. decay),(10^{-2}uc/cc)		1.04	0.40		0.20	0.20	0.022
Normal Operating Conditions							
17. MPC reactor release, uc/cc		$6x10^{-3}$	$6x10^{-3}$		$6x10^{-3}$	$6x10^{-3}$ (171)	$2x10^{-3}$ (167)
18. % of 10^6 curies permissible		21.4	33.3		50	50	46
19. MPC atomic blast, uc/cc		$9x10^{-3}$	$9x10^{-3}$		$9x10^{-3}$	$9x10^{-3}$ (1550)	$9x10^{-3}$ (14,500)
20. % of 10^6 curies permissible		87	184		450	450	4100

a. June minimum flow is not enough to produce stratification.

20-Day Spill of 10^6 Curies

Watts Bar Pool Elevation 740
(Stratified)

June Minimum Flow[a]

	Cl.			Em.	Cl.	Te.	
1. River	Cl.			Em.	Cl.	Te.	
2. Mile	20.8	13.2	4.4	12.8	0.0	567.7	529.9
3. Streamflow, cfs	224	224	247	14	262	8200	8200
4. Initial concentration (10^{-2}uc/cc)	9.12						
5. Time of travel (Tav.), days		14	36	None	55	55	87
6. First arrival (Tmin.), days		9.3	24		36.6	36.6	58
7. Duration downstream (X), days		45	66		85	85	117
8. Reduction peak by dilution, %		0					
9. Reduction peak by dispersion, %		0					
10. Reduction peak, total (excl.decay), %		0					
11. Corresponding peak, %		100					
12. Corresponding peak, (10^{-2} uc/cc)		9.1					
13. Ave.conc. (excl. decay),(10^{-2} uc/cc)		4.07					
14. $t = 1 + \text{Tmin.} + \frac{X}{2}$, days		32.8					
15. Decay factor to mid-duration ($t^{-1.2}$)		0.015					
16. Ave. conc. (incl. decay),(10^{-2} uc/cc)		0.061					
Normal Operating Conditions							
17. MPC reactor release, uc/cc		$2x10^{-3}$					
18. % of 10^6 curies permissible		4.9					
19. MPC atomic blast, uc/cc		$3x10^{-3}$					
20. % of 10^6 curies permissible		490					

June Mean Flow

	Cl.			Em.	Cl.	Te.	
1. River	Cl.			Em.	Cl.	Te.	
2. Mile	20.8	13.2	4.4	12.8	0.0	567.7	529.9
3. Streamflow, cfs	2820	2820	2890	396	3320	18,900	18,900
4. Initial concentration (10^{-2}uc/cc)	0.72						
5. Time of travel (Tav.), days		1.2	3.0	25	3.8	3.8	11.3
6. First arrival (Tmin.), days		0.8	2.0	24	2.5	2.5	7.5
7. Duration downstream (X), days		31.2	33.0	55	33.8	33.8	41.3
8. Reduction peak by dilution, %		0	(2.4) 0	(2.4) 0	(15) 0	85	85
9. Reduction peak by dispersion, %		0					
10. Reduction peak, total (excl.decay), %		0					
11. Corresponding peak, %		100					
12. Corresponding peak, (10^{-2} uc/cc)		0.72					
13. Ave.conc. (excl. decay),(10^{-2} uc/cc)		0.46	(0.43) 0.44	(0.26) 0.26	(0.36) 0.43	0.064	0.052
14. $t = 1 + \text{Tmin.} + \frac{X}{2}$, days		17.4	19.5	52.5	20.4	20.4	29.2
15. Decay factor to mid-duration ($t^{-1.2}$)		0.032	0.028	0.0086	0.027	0.027	0.018
16. Ave. conc. (incl. decay),(10^{-2} uc/cc)		0.015	0.012	0.0022	(0.01) 0.012	0.0017	0.0009
Normal Operating Conditions							
17. MPC reactor release, uc/cc		$1x10^{-3}$	$2x10^{-3}$		$2x10^{-3}$	$2x10^{-3}$	
18. % of 10^6 curies permissible		21.8	(47) 45		(56) 47	313	
19. MPC atomic blast, uc/cc		$9x10^{-3}$	$9x10^{-3}$		$9x10^{-3}$	$9x10^{-3}$	
20. % of 10^6 curies permissible		6000	7500		(9000) 7500	53,000	

June Maximum Flow

	Cl.			Em.	Cl.	Te.	
1. River	Cl.			Em.	Cl.	Te.	
2. Mile	20.8	13.2	4.4	12.8	0.0	567.7	529.9
3. Streamflow, cfs	7420	7420	7420	5300	9280	32,100	32,100
4. Initial concentration (10^{-2}uc/cc)	0.28						
5. Time of travel (Tav.), days		0.5	1.5	None	2.2	2.2	8.7
6. First arrival (Tmin.), days		0.33	1.0		1.5	1.5	5.8
7. Duration downstream (X), days		30.5	31.5		32.2	32.2	38.7
8. Reduction peak by dilution, %		0	0		20	(77) 20	(77) 20
9. Reduction peak by dispersion, %							
10. Reduction peak, total (excl.decay), %							
11. Corresponding peak, %							
12. Corresponding peak, (10^{-2} uc/cc)							
13. Ave.conc. (excl. decay),(10^{-2} uc/cc)		0.18	0.18		0.14	(0.04) 0.14	(0.033) 0.12
14. $t = 1 + \text{Tmin.} + \frac{X}{2}$, days		16.6	17.8		18.6	18.6	26.2
15. Decay factor to mid-duration ($t^{-1.2}$)		0.035	0.032		0.03	0.03	0.02
16. Ave. conc. (incl. decay),(10^{-2} uc/cc)		0.0063	0.0058		0.004	(0.0012) 0.004	(0.0007) 0.0024
Normal Operating Conditions							
17. MPC reactor release, uc/cc		$1x10^{-3}$	$1x10^{-3}$		$2x10^{-3}$	$2x10^{-3}$	$2x10^{-3}$
18. % of 10^6 curies permissible		56	56		143	(500) 143	(600) 167
19. MPC atomic blast, uc/cc		$9x10^{-3}$	$9x10^{-3}$		$9x10^{-3}$	$9x10^{-3}$	$9x10^{-3}$
20. % of 10^6 curies permissible		14,300	15,500		22,500	(69,000) 22,500	(128,500) 37,500

a. June minimum flow is not enough to produce stratification.

Appendix C

Explanation of Calculations in Appendixes A and B

6-Hour Spill of 10^6 Curies

1. Self-explanatory.
2. Self-explanatory.
3. For actual spill conditions, use actual flows obtained as explained under "Basic Data."

   For the purpose of illustration, streamflows from Table 1, Report No. 1, are used in the calculations of Appendixes A and B.

   (November minimum flows)

Cl. 20.8 and 13.2	453 cfs
Clinch (below Emory)	556 cfs
Cl. 0.0 (same as above)	556 cfs
Em. 0.0 = (2 cfs @ Em. 12.8) $\frac{865}{798}$	2 cfs
(Drainage area factor = $\frac{865}{798}$)	
Cl. 4.4 above Emory	554 cfs
Average Cl. 20.8 to 4.4	504 cfs
Te. 567.7 = Te. 529.9	10,300 cfs

   (November maximum flows)

   Since maximum flows do not necessarily occur simultaneously in the Clinch and the Emory Rivers, the above method should be modified to determine maximum in Clinch above Emory:

Assume runoff below Cl. 20.8 comparable to that on Emory watershed at Em. 12.8 = $\frac{27,800 \text{ cfs}}{798}$ = 34.8 cfs per square mile.

Then 34.8 (3541-3347) + 12,700 = 19,450 cfs @ Cl. 4.4

Ave. 20.8 to 4.4 = $\frac{12,700 + 19,450}{2}$ = 16,075

(June maximum flows)

This method is not applicable during June.

Reasoning: Maximum flow in Clinch River during summertime will most probably be due to releases from Norris. Side drainage will be small in proportion to high releases from Norris. Therefore, consider maximum flow in Clinch River to be the same at Cl. 20.8, Cl. 13.2, and Cl. 4.4 above Emory.

4. Initial concentration

1 cfs = 28,320 cc/sec. = 101,952,000 cc/hr.

453 cfs for 6 hrs. = 453 x 6 x 101,952,000 = 277,105,536,000 cc

10^6 curies in 6 hrs. = $\frac{10^6 \text{ C} \times 10^6 \mu c/C}{277,105,536,000}$ = 360.87×10^{-2} μc/cc

5. Plates 2 and 3, Report No. 1, curves for elevation 736 (non-stratified). Plate 5 (stratified).

For Cl. 20.8 to 4.4 use average flow in the reach.

For Tennessee River see page 8, Report No. 1. The chart on Plate 22 has been prepared for use when Clinch River flow is below 6000 cfs.

For Te. 529.9 to Te. 465.3 use Plate 4.

For Emory River use Plate 23.

6. $T_{min.} = \frac{2}{3}$ Tav., page 16, Report No. 2. (For Emory River also use Plate 23, Report No. 3.)

7. X = Tav. + (1.5 x duration of release), page 16, Report No. 2.

8. e.g., $\frac{4640 - 4430}{4640} = 4.5\%$ @ Cl. 4.4.

   Note: For stratified flow there would be no appreciable reduction by dilution in the density underflow. However, when considering the entire cross-section, it would be calculated at Cl. 0.0 $\frac{3320 - 2820}{3320} = 15\%$. The figures in parentheses are for reduction in the entire cross-section. Assume the same concentration in the Emory River as in the Clinch underflow.

9. Using Cl. flow @ mile 20.8, read values from plates 12-16, inclusive, Report No. 1. See Table 2, Report No. 1 for stratified flows.

   For example: Cl. 20.8 to Cl. 4.4 = 48%.

10. $100 [1 - (1.00 - 0.24)(1.00 - 0.65)] = 73.4\%$.

11. 100% - 73.4% = 26.6%.

12. Initial concentration x corresponding peak

    e.g., 36.9×10^{-2} µc/cc x 26.6% = 9.8×10^{-2} µc/cc.

13. $\frac{\text{Initial concentration x (100\% - \% reduction by dilution) x duration of release}}{\text{Duration downstream}}$

    e.g., $\frac{36.9 \times 10^{-2} \times (100\% - 4.5\%) \times 0.25}{2.2} = 4.0 \times 10^{-2}$ µc/cc

14. Note: Assume one day decay before release and calculate decay for time elapsed to midpoint of duration downstream.

e.g., t (assumed decay time) = 1 + Tmin. + $\frac{X}{2}$, where X = duration downstream (line 7) = 1 + 1.2 = $\frac{2.2}{2}$ = 3.3 days.

15. Decay factor to mid-duration = $t^{-1.2}$

$3.3^{-1.2} = 0.24$

16. Average concentration (including decay)

line 13 x line 15 = $4.0 \times 10^{-2} \times 0.24 = 0.96 \times 10^{-2}$ µc/cc

17. Using time of first arrival and duration at a downstream point, enter Table 8, Report No. 3, and determine appropriate value of MPC for the period of use and interval after spill.

e.g., Reactor release for 2.2 days use beginning 1.2 days after spill. MPC = 6×10^{-3} µc/cc.

18. Line 17 ÷ line 13

e.g., 6×10^{-3} µc/cc ÷ 4.0×10^{-2} µc/cc = 15%.

19. Determined same way as line 17 except for atomic blast.

20. Line 19 ÷ line 16

e.g., 9×10^{-3} µc/cc ÷ 0.96×10^{-2} µc/cc = 94%.

21. Assume 25,000 cfs is maximum flow in Clinch River without flooding shore installations and that Norris release plus local inflow totals 25,000 cfs at Cl. 20.8.

22. Plate 24, time of wave or water from Norris to Cl. 20.8. Data for plotting curves obtained from "Translatory Waves in Natural Channels," J. H. Wilkinson, Trans. ASCE, 1945, Vol. 110, p. 1203. Determine time of flow to downstream points by use of Plates 2, 3, 4, 5, 22, and 23 as in line 5.

23. Duration = Tmin. + 1.5 x ~~duration~~ of release

e.g., X = line 22 + 1.5 x (6 hrs.) = .37 + 1.5 x (.25)

= 0.75 days @ Cl. 4.4.

24. Similar to line 13.

$$\frac{\text{Initial conc. x duration of release x (100\% - \% reduction by dilution)}}{\text{duration downstream}}$$

$$= \frac{36.9 \times 10^{-2} \times 0.25 \times \left(100\% - \frac{25{,}000 - 4430}{25{,}000}\right)}{0.75} = \frac{9.2 \times 10^{-2} \times (100\% - 80\%)}{0.75}$$

$= 2.4 \times 10^{-2}\ \mu c/cc$

Note: This reduction by dilution is based on 25,000 cfs Norris release.

25. MPC ÷ line 24 = $6 \times 10^{-3} \div 2.4 \times 10^{-2}$ = 25%.

26. $t^{-1.2} = (1 + \frac{2}{3}\, 0.37 + \frac{0.75}{2})^{-1.2} = 1.62^{-1.2} = 0.56$

27. Line 26 x line 24 = $0.56 \times 2.4 \times 10^{-2} = 1.35 \times 10^{-2}\ \mu c/cc$

28. MPC ÷ line 27 = $9 \times 10^{-3} \div 1.35 \times 10^{-2}$ = 67%.

29. Refer to appropriate month and location in Table 5, Report No. 2.

30. 745 - existing lake level. For this study 745 - 736 = 9 ft. non-stratified and 745 - 740 = 5 ft. stratified.

31. From line 30 mean daily local inflow November

Cl. 20.8 = 480

Cl. 4.4 = 700

Ave. = 590 cfs. Enter Plate 18 (for Cl. 4.4 and other plates accordingly) with this flow and determine Tmin. = 21 days. Note: For Te. 529.9 add to the time of retardation in the Clinch embayment the time of travel from Te. 567.7 to Te. 529.9 as determined from Plate 3 for non-stratified flow or from Plate 22 during stratified flow. For conditions not shown on Plate 22, refer to pages 7 and 8, Report No. 1.

32. Duration = 1.5 (Tmin. + D) = 1.5 (21 + 0.25) = 31.9 days

33. Figured as in line 13.

$$\frac{360.87 \times 10^{-2} \times \left(100\% - \frac{700 - 453}{700}\right) \times 0.25}{31.9} = 1.83 \times 10^{-2}\ \mu c/cc$$

34. MPC from Table 8, Report No. 3, ÷ line 33

$2 \times 10^{-3} \div 1.83 \times 10^{-2} = 10.9\%.$

35. $t = \text{Tmin.} + \frac{X}{2} + 1$

$= \text{line } 31 + \frac{1}{2} \text{ line } 32 + 1$

$= 21 + 16 + 1 = 38$ days

36. $t^{-1.2} = 38^{-1.2} = 0.013$

37. Line 36 x line 33 = $0.013 \times 1.83 \times 10^{-2} = 0.024 \times 10^{-2}$ μc/cc

38. MPC ÷ line 37 = $3 \times 10^{-3} \div 0.024 \times 10^{-2}$ = 1250%.

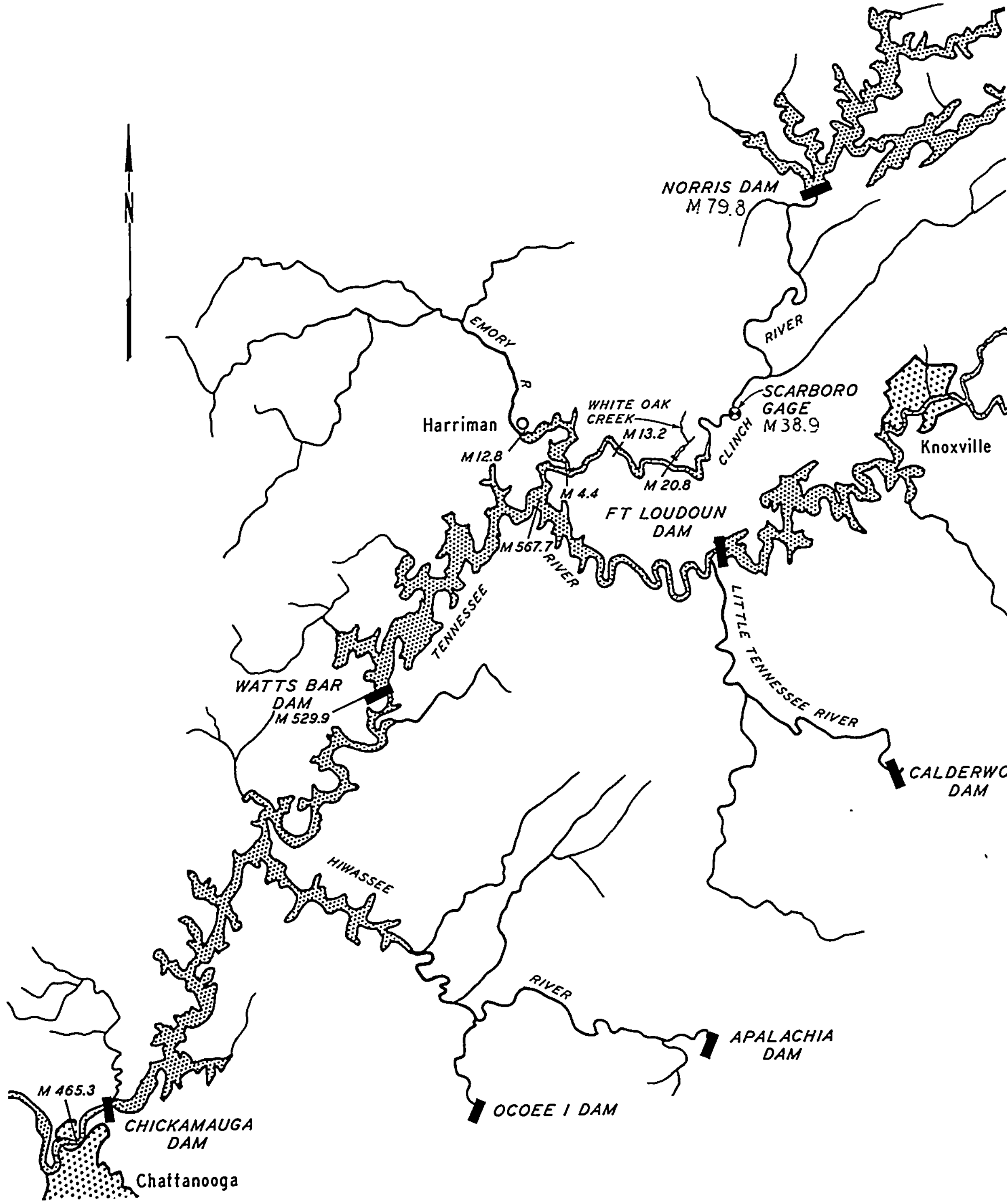
Tennessee Valley Authority
Division of Health and Safety
Environmental Hygiene Branch

TABLE 9

Calculation Sheet

Expected duration of spill into Clinch: From __________ Until __________
Quantity of spill __________ Total __________ (hrs) (days)
Elevation Watts Bar Reservoir ___
(Stratified) (Non-Stratified) ___

1.	River	Cl.	Cl.	Cl.	Em.	Cl.	Te.	Te.	Te.
2.	Mile	20.8	13.2	4.4	12.8	0.0	567.7	529.9	465.3
3.	Streamflow, cfs								
4.	Initial concentration (10^{-2} μc/cc)								
5.	Time of travel (Tav.), days								
6.	First arrival (Tmin.), days								
7.	Duration downstream (X), days								
8.	Reduction of peak by dilution, %								
9.	Reduction of peak by dispersion, %								
10.	Reduction peak, total (excl.decay),%								
11.	Corresponding peak, %								
12.	Corresponding peak (10^{-2}μc/cc)								
13.	Ave. conc. (excl.decay)(10^{-2} μc/cc)								
14.	$t = 1 + \text{Tmin.} \times \frac{X}{2}$, days								
15.	Decay factor to mid-duration($t^{-1.2}$)								
16.	Ave. conc. incl. decay (10^{-2} μc/cc)								
17.	MPC reactor release (μc/cc)								
18.	% of spill permissible								
19.	MPC atomic blast (μc/cc)								
20.	% of spill permissible								



TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

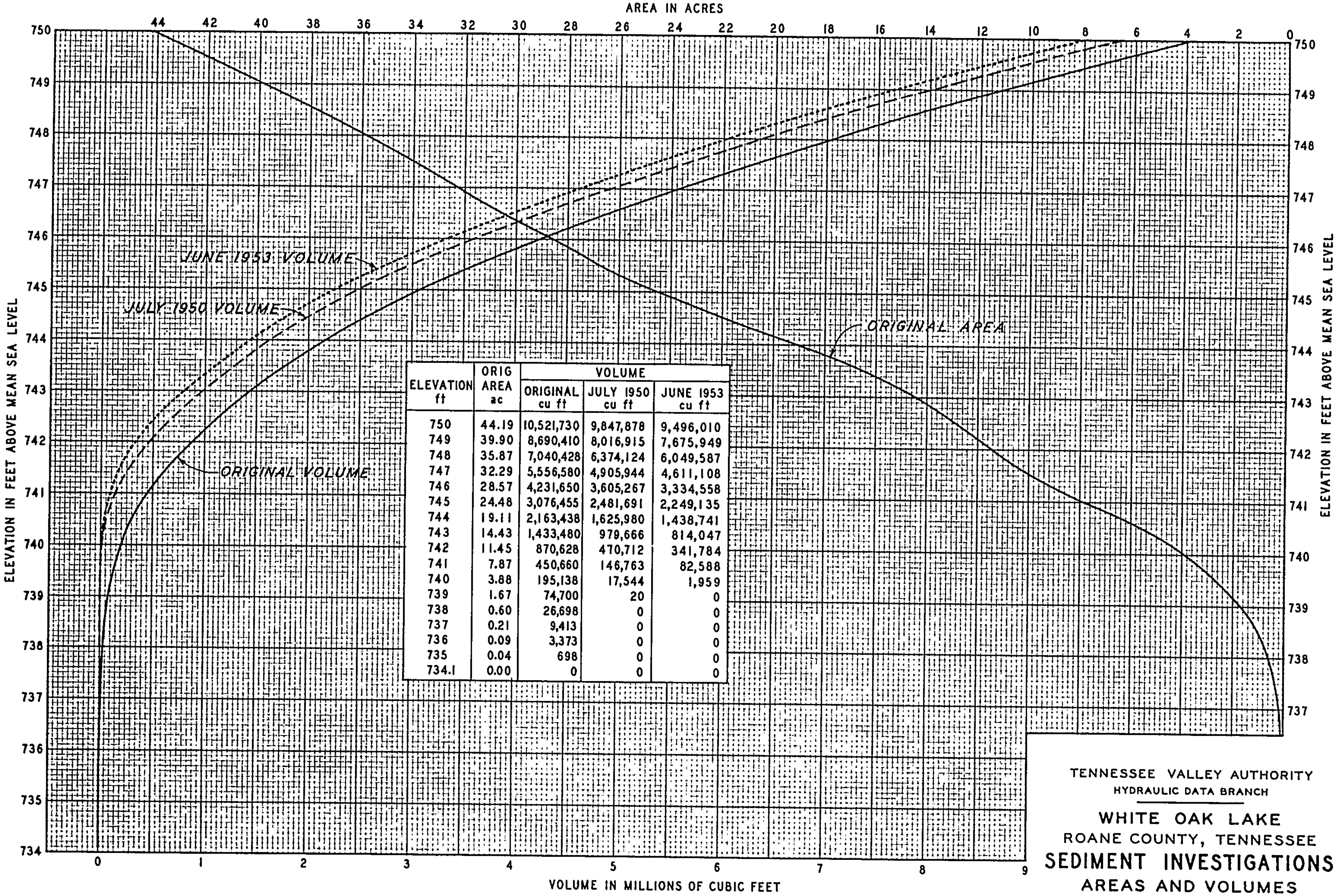
AEC SPILLAGE STUDY

LOCATION MAP

Scale 0 10 20 30 Miles

OCTOBER 6, 1952

ASF 1256

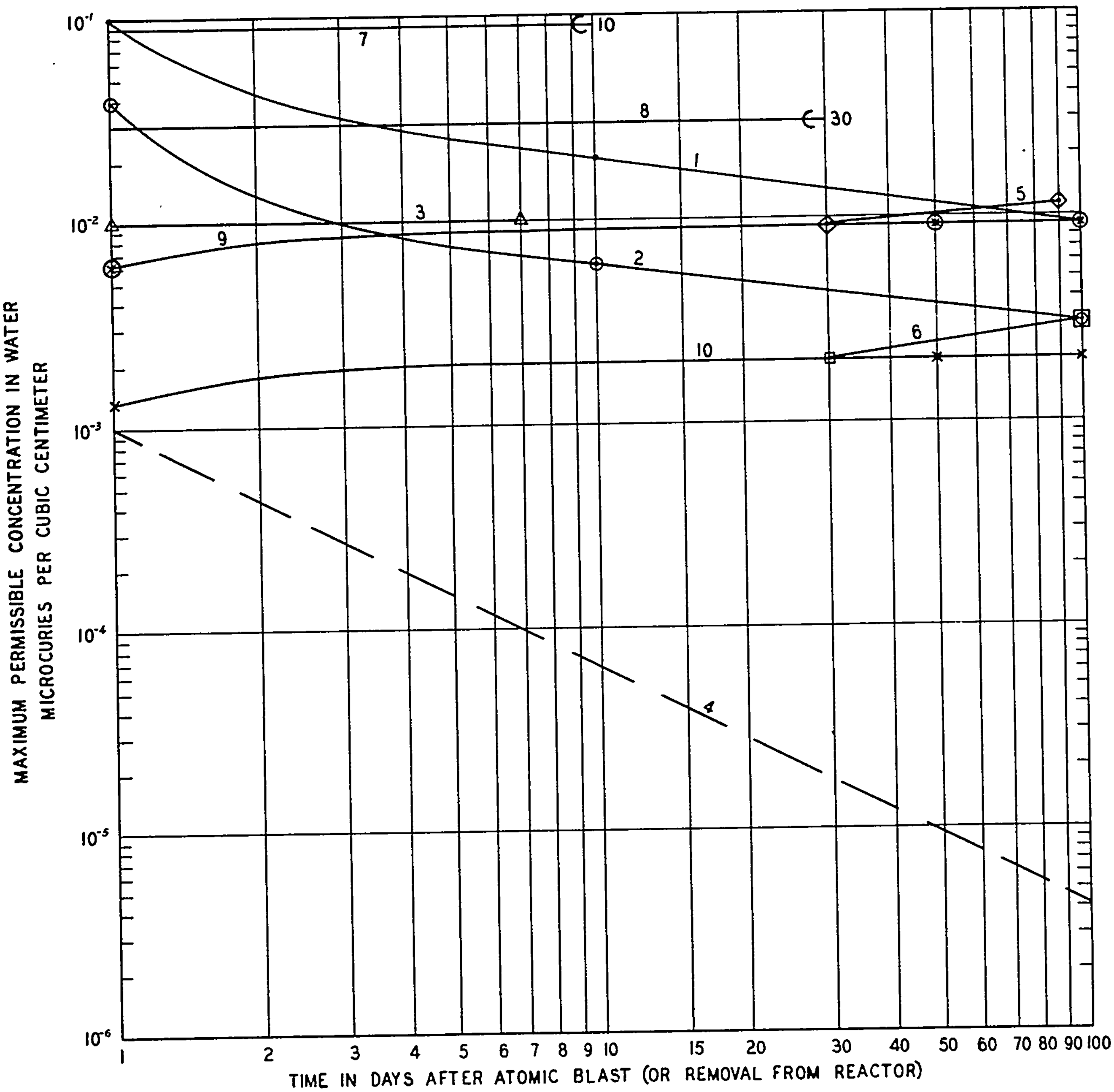


ELEVATION ft	ORIG AREA ac	VOLUME ORIGINAL cu ft	VOLUME JULY 1950 cu ft	VOLUME JUNE 1953 cu ft
750	44.19	10,521,730	9,847,878	9,496,010
749	39.90	8,690,410	8,016,915	7,675,949
748	35.87	7,040,428	6,374,124	6,049,587
747	32.29	5,556,580	4,905,944	4,611,108
746	28.57	4,231,650	3,605,267	3,334,558
745	24.48	3,076,455	2,481,691	2,249,135
744	19.11	2,163,438	1,625,980	1,438,741
743	14.43	1,433,480	979,666	814,047
742	11.45	870,628	470,712	341,784
741	7.87	450,660	146,763	82,588
740	3.88	195,138	17,544	1,959
739	1.67	74,700	20	0
738	0.60	26,698	0	0
737	0.21	9,413	0	0
736	0.09	3,373	0	0
735	0.04	698	0	0
734.1	0.00	0	0	0

TENNESSEE VALLEY AUTHORITY
HYDRAULIC DATA BRANCH

WHITE OAK LAKE
ROANE COUNTY, TENNESSEE
SEDIMENT INVESTIGATIONS
AREAS AND VOLUMES

JUNE 1953

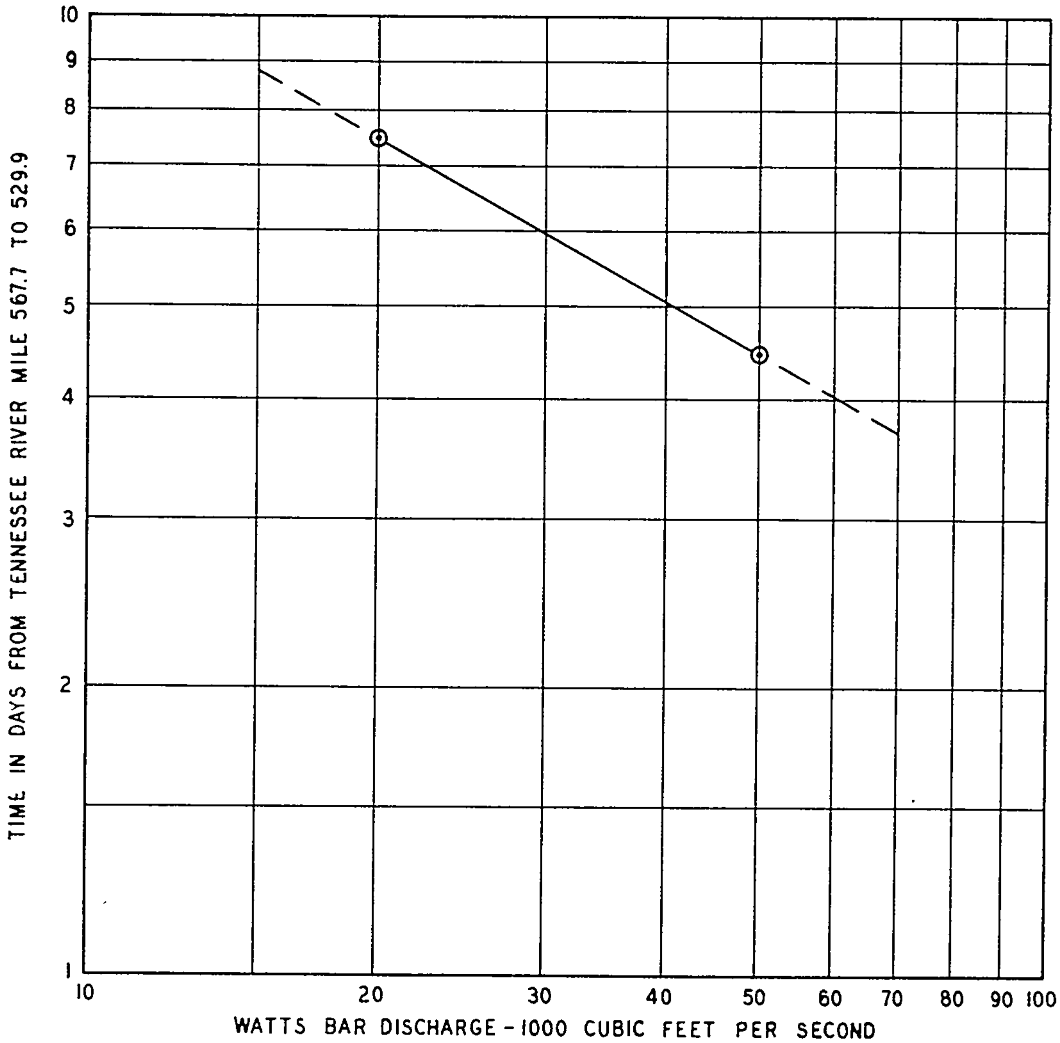


LEGEND

INCIDENT		AUTHORITY	PERIOD OF USE
1. ATOMIC BLAST	—•—	STRAUB	1 DAY
2. " "	—⊖—	STRAUB	30 DAYS
3. " "	—△—	MORGAN	7 DAYS
4. " "	— — —	MORGAN	$MPC = Kt^{-1.2}$
5. " "	—◇—	PARKER	7 DAYS
6. " "	—□—	PARKER	30 DAYS
7. " "	—∈10	FCDA	FIRST 10 DAYS
8. " "	—∈30	FCDA	FIRST 30 DAYS
9. REACTOR RELEASE	—⊗—	PARKER	7 DAYS
10. " "	—x—	PARKER	30 DAYS

TENNESSEE VALLEY AUTHORITY
DIVISION OF HEALTH AND SAFETY
ENVIRONMENTAL HYGIENE BRANCH

MAXIMUM PERMISSIBLE CONCENTRATION
OF
RADIOACTIVE WASTES
IN
DRINKING WATER



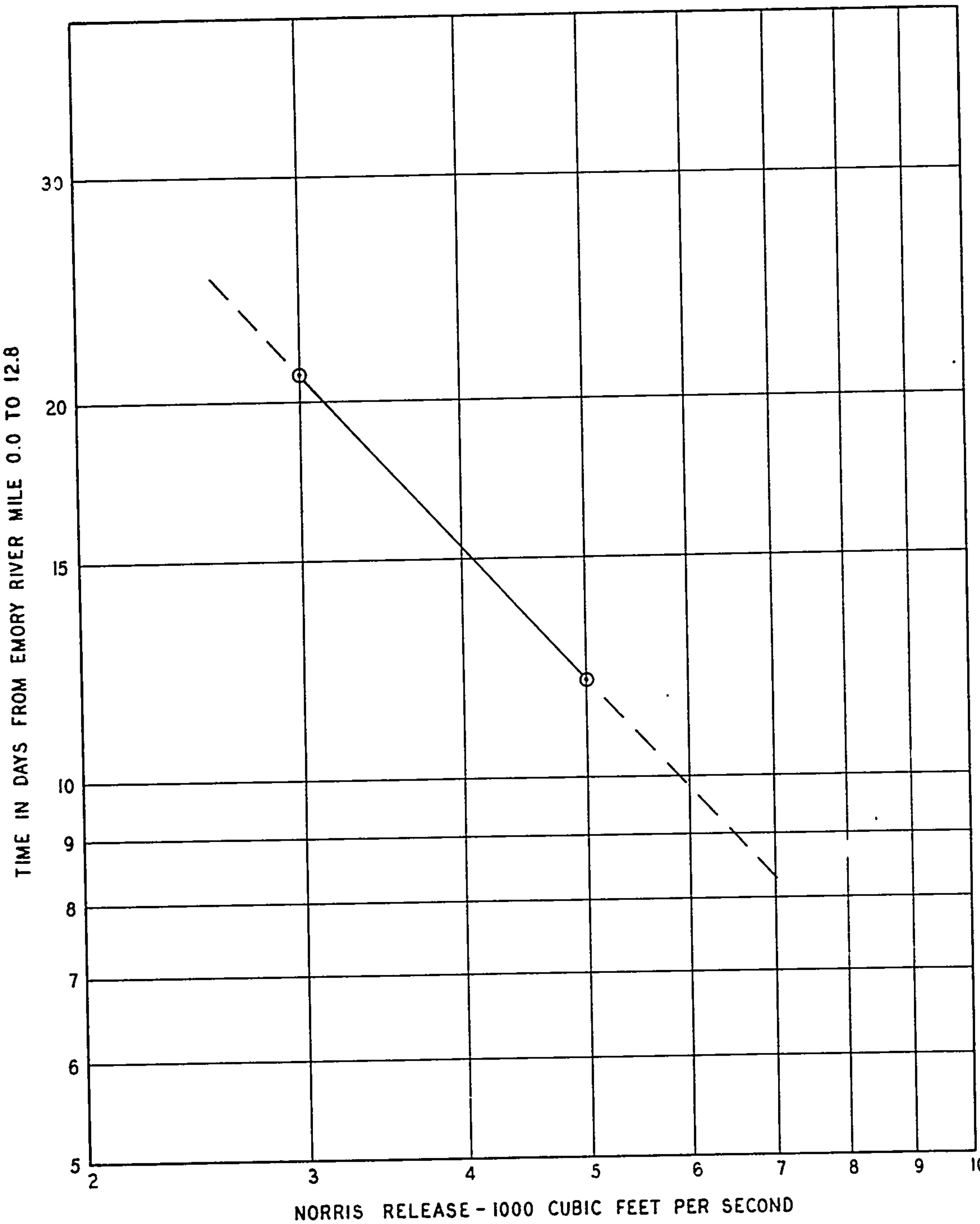
FOR USE WHEN CLINCH RIVER FLOW IS LESS THAN 6,000 CFS.

TENNESSEE VALLEY AUTHORITY
DIVISION OF HEALTH AND SAFETY
ENVIRONMENTAL HYGIENE BRANCH

TENNESSEE RIVER

TIME OF WATER TRAVEL

MILE 567.7 TO 529.9
STRATIFIED FLOW



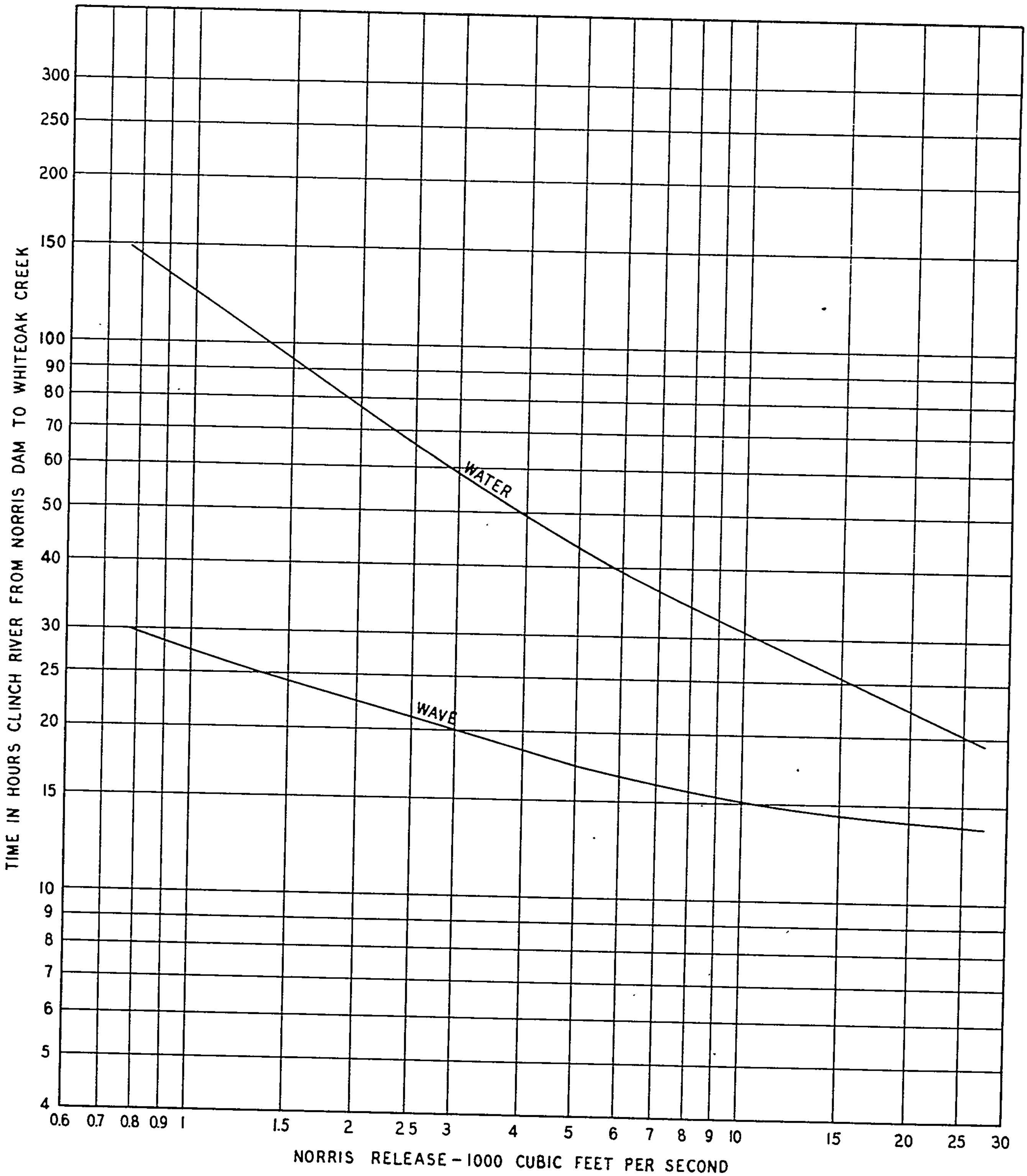
UPSTREAM FLOW IN EMORY DEVELOPS ONLY WHEN CLINCH RIVER FLOW IS BETWEEN 3,000 AND 7,000 CFS.

TENNESSEE VALLEY AUTHORITY
DIVISION OF HEALTH AND SAFETY
ENVIRONMENTAL HYGIENE BRANCH

EMORY RIVER

TIME OF WATER TRAVEL

MILE 0.0 TO 12.8
STRATIFIED FLOW



TENNESSEE VALLEY AUTHORITY
DIVISION OF HEALTH AND SAFETY
ENVIRONMENTAL HYGIENE BRANCH

CLINCH RIVER
TIME OF WATER TRAVEL
NORRIS TO WHITEOAK CREEK